U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-276 639

The Cost of Water Supply and Water Utility Management
Volume I

ACT Systems, Inc, Winter Park, Fla

Prepared for

Municipal Environmental Research Lab, Cincinnati, Ohio

Nov 77

PB 276 639

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SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/5-77-015a

2.

3. RECIPIENT'S ACCESSION NO.
PB276639

4. TITLE AND SUBTITLE
THE COST OF WATER SUPPLY AND WATER UTILITY MANAGEMENT
Volume I

5. REPORT DATE
November 1977 (Issuing Date)

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
ACT Systems, Inc.
807 West Morse Blvd.
Winter Park, Florida 32789

10. PROGRAM ELEMENT NO.
1CC614, SOS 1

11. CONTRACT/~~GRANT~~ NO.
68-03-2071

12. SPONSORING AGENCY NAME AND ADDRESS
Municipal Environmental Research Laboratory--Cin.,OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Extramural

14. SPONSORING AGENCY CODE
EPA/600/14

15. SUPPLEMENTARY NOTES
See also Volume II, EPA-600/5-77-015b
Project Officer: Robert M. Clark, WSRD, Cincinnati, Ohio 45268, 513/684-7209

16. ABSTRACT

A Study of 12 selected water utilities was undertaken to determine the economics of water delivery. Data were collected from at least one Class A water utility (Revenues greater than $500,000/year) in each of the U.S. Environmental Protection Agency's 10 regions. These data are presented in a two-volume report. Volume I provides summary information and in-depth analysis of the 12 utilities studied. All the uilities are analyzed in aggregate, and factors affecting the cost of water supply are examined. Also provided is an evaluation of the hypothetical impact of a proposed organic regulation, promulgated under the Safe Drinking Water Act, in 1980.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Benefit Cost Analysis; Cost Analysis; Economic Analysis; Forecasting; Mathematical Models; Regional Planning; Systems Analysis; Urban Planning; Water Distribution; Water Supply	Organic Standards; Standardized Cost Categories; Trends--Water Supply Costs; Water Production Costs; Water Utility Management	13 B 14 A

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 181
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE PCA09 MF A01

EPA Form 2220-1 (Rev. 4-77)

U.S. GOVERNMENT PRINTING OFFICE: 1977— 757-140/6612

EPA-600/5-77-015a
November 1977

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Volume I

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and interplay among its components require a concentrated and integrated attack on the problem.

Research and development is that first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems (1) to prevent, treat, and manage wastewater, solid and hazardous waste, and pollutant discharges from municipal and community sources, (2) to preserve and treat public drinking water supplies, and (3) to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is a product of that research and is a most vital communications link between the researcher and user community.

The Safe Drinking Water Act of 1974 establishes primary, health-related standards and secondary, aesthetic-related but nonenforceable guidelines for drinking water supplies. These standards will bring about fundamental changes in the way water is handled before it is delivered to the consumer. Many of these changes will have an economic impact on the affected water utilities. This report provides detailed information on the current costs of water supply for 12 selected water utilities. In addition to providing information on the individual supplies, data are aggregated to provide projections of the relative impact of various strategies that might be undertaken to satisfy the Act's requirements. These data and associated analyses are presented in two volumes. Volume I is a summary of selected data from the study together with its analysis. Volume II contains detailed, in-depth information for each utility studied.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory

ABSTRACT

A study of 12 selected water utilities was undertaken to determine the economics of water delivery. Data were collected from at least one class A water utility (revenues greater than $500,000/year) in each of the U. S. Environmental Protection Agency's 10 regions. Volume I provides summary information and in-depth analyses of five of the 12 utilities studied. All the utilities are analyzed in aggregate, and factors affecting the cost of water supply are examined. Also provided is an evaluation of the hypothetical impact of the Safe Drinking Water Act in 1980.

Volume II contains the basic data from each of the 12 utilities studied. Services of each utility were divided into five functional areas common to all water supply delivery systems -- support services, acquisition, treatment or purification, distribution, and power and pumping. These areas provided a common basis for collecting and comparing data. Costs were categorized as operating or capital expenditures.

This report was submitted in fulfillment of Contract No. 68-03-2071 by ACT Systems, Inc., under the sponsorship of the U. S. Environmental Protection Agency. The report covers the period July 1974 to July 1976, and work was completed as of September 1977.

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METRIC CONVERSION TABLE

English Units	Metric Equivalents
1 foot	0.305 meters
1 mile	1.61 kilometers
1 square mile	2.59 square kilometers
1 million gallons	3.79 thousand cubic meters
1 $/million gallons	0.26 $/thousand cubic meters
1 ¢/1000 gallons	0.26 ¢/cubic meter

ACKNOWLEDGEMENTS

The cooperation, active support, and sustained interest of many people made the study described in this report possible. In particular, the following individuals should be acknowledged.

From the regional offices of the U. S. Environmental Protection Agency:

Floyd Taylor and Charles Larsen of Region I
Everett L. MacLeman, formerly of Region II
James Manwaring, formerly of Region III
Gary D. Hutchinson and Curt Fehn of Region IV
Joseph Harrison of Region V
Charles Sever and Warren Norris of Region VI
Otmar O. Olson and Aleck Alexander of Region VII
Albert V. Soukop, formerly of Region VIII
Robert Scott of Region IX
William A. Mullen of Region X

From the participating water utilities:

Henry J. Graeser, Director, Robert G. Ford, Assistant Director, and Larry Shaw, Accountant, Dallas Water Utilities
Henry S. Patterson, President, Chester A. Ring, Vice President (Operations), Bob Palasits, Director of Planning, Elizabethtown Water Company
James F. Corbalis, Jr., Director, Vincent Bryne, Fairfax County Water Authority
Donald R. Boyd, Director, H. E. Snider, Assistant Director, J. R. Popalisky, Chief, Water Supply Division, Kansas City Missouri Water Department
Victor C. Fender, General Manager, Mal Connett Office Manager, Kenton County Kentucky Water District No. 1
Charles E. Woods, President, Richard P. McHugh, Vice President for Engineering, New Haven Water Company
Ted Pope, Manager Water Operations, Bob Savarese, Applications Engineer, Orlando Water Utility
Art F. Vondrick, Director, Philip S. Slagel, Assistant Director, Phoenix Water Department

Larry C. Fountaine, Director, Craig A. Olsen, Engineer, Pueblo Board of Water Works
R. W. King, Director, Ernie Clay, Assistant Director, San Diego Water Utilities Department
Kenneth M. Lowthian, Superintendent, James T. Rice, Assistant Superintendent, Seattle Water Department
Charles Bolton, former Superintendent, Dan Merwin, former Special Assistant to the Superintendent, and William F. Reeves, Chief Engineer, Cincinnati Water Works

Special acknowledgements are extended to Mr. Ted Pope, Manager of Water Operations, Orlando Water Utility, for his review in the formative stages of this study, and for the continuing assistance of Messrs. John N. English, Leland J. McCabe, and Gregory D. Trygg, and Drs. James M. Symons and Richard G. Stevie of the EPA in Cincinnati.

Dr. Billy P. Helms, Assistant Professor of Finance, University of Alabama, Mr. Nolan Reed, President of Nolan Reed Associates, Orlando, Florida, Dr. Carl Kessler of EPA's Office of Water Supply, provided in-depth reviews of the final report from this project. Mrs. Louise Fischer of EPA in Cincinnati typed and Mrs. Ann Hamilton edited this manuscript.

SECTION 1

EXECUTIVE SUMMARY

A two-year study of 12 selected water utilities was undertaken to determine the economics of water delivery. Data were collected from at least one class A water utility (revenues greater than $500,000/year) in each of U. S. Environmental Protection Agency's (EPA) 10 regions. The finished water from all utilities selected meets the 1962 Public Health Service Drinking Water Standards. Volume I of this report provides in-depth analyses for five of the 12 utilities studied: Cincinnati, Ohio; Kansas City, Missouri; Fairfax County Water Authority in Fairfax, Virginia; Dallas, Texas; and the Elizabethtown Water Company in Elizabeth, New Jersey. Aggregate analysis of data from all the utilities is also provided in Volume I, along with an evaluation of factors affecting the cost of water supply and a consideration of the impact of technologies that might be used to satisfy requirements of the Safe Drinking Water Act.

Volume II contains the basic data from each of the 12 utilities studied. They represent many institutional arrangements, physically different water supply systems, and different conditions faced by water utilities across the United States. For example, Cincinnati and Kansas City are single-source utilities distributing water to far-flung distribution areas. Others, such as the Dallas Water Utility and the Fairfax County Water Authority, are in rapidly growing areas with capital costs distributed over a fast-growing, revenue-producing base that keeps water costs low. Two investor-owned utilities, Elizabethtown Water Company and New Haven Water Company, were included in the sample to demonstrate problems associated with investor-owned utilities. The San Diego and Phoenix utilities operate in water-short areas. Pueblo and Kenton County were the smallest utilities studied. Seattle has made extensive investments in controlled source protection, and Orlando uses groundwater from a deep aquifer.

Data were collected for 10 years in five operating cost categories and two capital cost categories. The operating cost categories are support services, acquisition, treatment, power and pumping, and transmission and distribution. Capital costs were divided into interest and depreciation. Each operating cost category was examined as to total expenditures, unit costs, and percent of total cost. Revenue-producing water was used for all cost calculations because it represents the basis on which utilities obtain their operating revenues, and provides the real basis for comparing productivity and costs between systems. Systems vary in the proportion of water sold, meaning that uncertainties are introduced in the comparison of unit cost and productivity over time for a single utility. To convert to a basis of water produced, a simple conversion based on the ratio of water sold to water produced can be used. The impact of operating expenditures, increasing labor costs, and increasing labor productivity on total water production costs were examined.

A systems evaluation was made for each utility in which the service area was divided into its components. Schematic diagrams of the system components have been developed for each of the utilities studied. For some utilities, these diagrams are very detailed, and for others, because of the complexity of the system, the diagram is somewhat superficial. By using the systems diagram and the previous cost categorizations, it was possible to evaluate the costs associated with delivering water to various subsections of the distribution system and to make some estimates as to how the costs of water vary throughout the distribution area.

Individual and comparative analyses reveal certain trends. Labor cost is a significant part of the annual operating costs for all utilities and has nearly doubled in some cases over the period of analysis. More and more dollars are being shifted into support service activities. Examination of water delivery costs shows that they increase with the distance from the treatment plant; thus there are definite limits to the efficient size of water utility service areas.

Mathematical models have been developed that relate labor cost ($/man-hour), productivity (man-hours/million gallons (MG), and production (revenue-producing water) to annual operating costs. Another model has been developed for annual capital costs incorporating revenue-producing water and depreciation.

Extrapolations have been made with historical data for future water costs. Estimates for meeting the Safe Drinking Water Act's organic standards have been superimposed on these costs. Between 1975 and 1980, and using data from this study, it is estimated that the price of water will have increased by 36% as a result of normal inflation and increased demands. For those few utilities required by the Safe Drinking Water Act to install the most expensive control technology (granular activated carbon), costs will increase an additional 24% above the expected 1980 levels.

Total costs for each of the 12 utilities during the latest year of data collection are shown in Table 1. Taxes for the investor-owned utilities are reported separately. Table 1 also contains the name and average distribution for the utilities studied so that in using this document one can examine the data for a specific utility as contained in Volume II.

We hope these data will provide useful information on water supply costs from various utility systems and an example of the means by which data can be collected from water supplies to provide comparative information. With the advent of the Safe Drinking Water Act, regulatory agencies, utility managers, and the public should be able to isolate and understand various cost impacts on utilities of inflation and expansion demand versus regulatory impacts.

TABLE 1. COST ANALYSIS SUMMARY FOR LATEST YEAR OF RECORD (1974)

Utility	Revenue-producing water (mil gal/day)	Cost categories ($/mil gal)					
		Support services	Acquisition	Treatment	Distribution	Interest	Total
Kansas City	26,855	$ 145	$ 15	$ 82	$ 138	$ 50	$ 430
Dallas	63,030	83	25	52	120	58	338
San Diego	47,192	96	277	28	106	7	514
New Haven	17,714	113	29	15	106	117	560*
Fairfax Co.	19,232	88	35	56	134	209	522
Phoenix	63,661	91	17	47	112	53	320
Kenton Co.	2,259	82	12	103	124	73	394
Orlando	12,522	110	42	22	135	85	394
Elizabeth	38,256	89	67	33	144	113	492+
Pueblo	6,793	99	38	84	232	164	617
Seattle	45,967	109	37	13	77	27	263
Cincinnati	38,104	85	17	36	139	18	295

* Includes $179 taxes.

+ Includes $76 taxes.

The approach suggested here will allow the utility manager to pinpoint areas where costs are spiraling out of control and allow him to take corrective action. Table 2 summarizes some of the expected cost increases resulting from inflation and demand, as well as the effects of add-on technologies.

TABLE 2. EXPECTED INCREASE IN COSTS FOR 1980
Based on Data from Study

Item	Cost in 1975	Expected cost in 1980	1980 costs with add-on technologies		
			GAC - contactors	GAC - media replacement	Chlorine dioxide
Treatment operating cost ($/yr in millions)	1.10	1.50	2.97	4.17	2.17
Treatment capital cost ($/yr in millions)	0.48	0.60	3.34	1.33	0.73
Total operating cost ($/yr in millions)	8.85	12.40	13.87	15.07	13.07
Total capital cost ($/yr in millions)	3.80	4.95	7.69	5.68	5.08
Total production cost ($/yr in millions)	12.75	17.35	21.56	20.75	18.25
Total unit cost ($/mil gal)	412.00	480.00	596.47	574.06	504.90

SECTION 2

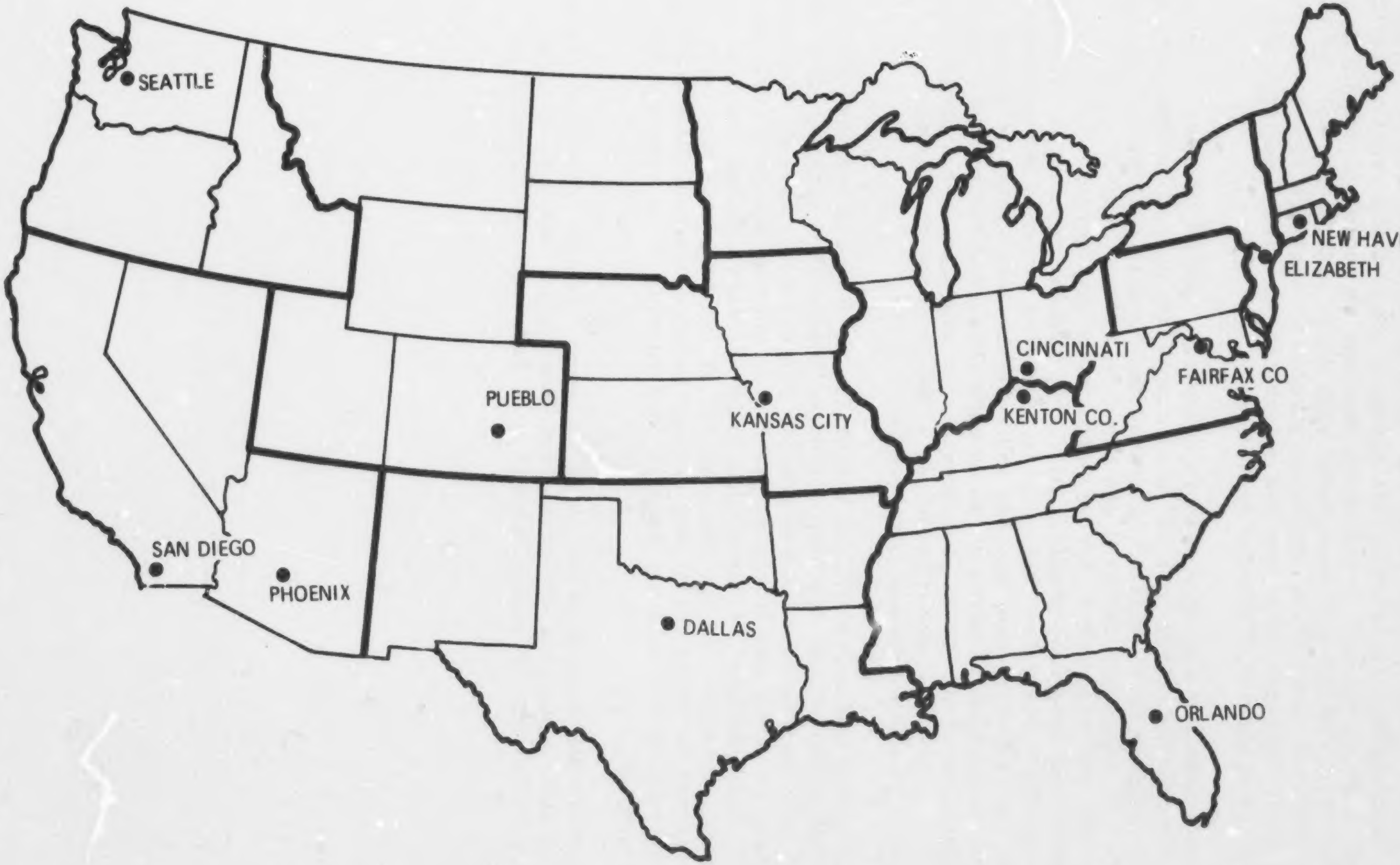
INTRODUCTION

The Safe Drinking Water Act of 1974 will bring about a fundamental examination of the way drinking water is handled before it is delivered to consumers.[1] The Act establishes primary health-related standards and secondary or aesthetic-related, but nonenforceable, guidelines for drinking water supplies. Throughout the Act, emphasis is placed on the need to consider the economics of water delivery.[2]

In response to this need, a two-year study of selected water utilities was undertaken in which data were collected from at least one class A water utility (revenues greater than $500,000/yr) in each of the U. S. Environmental Protection Agency's (EPA) 10 regions.[3] Figure 1 shows the locations of utilities studied. Twelve utilities were selected for investigation -- one in regions I, II, III, V, VI, VII, VIII, and X, and two in regions IV and IX. The study, which ran from 1974 through 1976, was conducted in two phases, with a special study in Cincinnati, Ohio. Data were collected so that costs could be easily compared among utilities.

Each utility's services were divided into the functional areas of acquisition, treatment or purification, and distribution. These functional areas or subsystems are common to all water supply delivery systems and can therefore provide a common basis for data collection. Another category common to all water utilities is the management or administrative function, which completes the framework of the institution for insuring an adequate supply of safe drinking water. This institution is most commonly called a water supply utility.

Costs were categorized as either operating or capital expenditures. Operating costs have been assigned to the following functional areas: acquisition, treatment, power and pumping, transmission and distribution (including storage), and support services. The first four functional areas are related to the physical delivery of water, and the fifth, support services, is related to the overall integrative responsibility of utility management. Operating costs include operating labor, maintenance, and materials. For example, if the utility has a treatment division, laboratory personnel costs are included in the treatment cost category, but management costs for the division are included in the support services category. Support services include, therefore, all of the administrative and customer services that are required to manage the water utility and collect revenues but that are not directly related to the physical process of delivering water.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ORLANDO

FIG. 1 LOCATION OF WATER UTILITIES STUDIED

Capital costs are assumed as depreciation and interest for the plant-in-service. Depreciation is based on the historic cost of the facility divided by its useful life, and not on the costs required to reproduce the facility. Lower costs will therefore be associated with older utilities. Most of the utilities analyzed constructed the major portion of their facilities in the 1930s and 40s. Interest costs are the dollars the utilities must pay for their bonds or other money-raising mechanisms.

Revenues were not considered in this report. All of the data reported are strictly related to the cost of water supply and do not include some of the broader aspects of elasticity of demand and optimal pricing policies of water supply.[4] All costs reported are based on revenue-producing water pumped by the utilities for a 10-year period from 1965 through 1974. Revenue-producing water was used for all cost calculations because it represents the basis on which utilities obtain their operating revenues and provides the real basis for comparing productivity and costs between systems. Systems vary in the proportion of water sold, meaning that uncertainties are introduced in the comparison of unit cost and productivity over time for a single utility. To convert to a basis of water produced, a simple conversion based on the ratio of water sold to water produced can be used.

The finished water from all of the utilities selected for the study meets the 1962 Public Health Service Drinking Water Standards. Although efficiency of removal and the raw water source quality influence the cost of treatment, these factors were not explicitly considered as part of the data collection effort. An equation has been developed, however, that relates chemical costs to the quality of source water. Because all of the utilities meet with 1962 standards it can be assumed that any changes required to meet SDWA standards will be incremental and will not involve construction of an entirely new treatment complex.

The report has been prepared in two volumes. Volume I contains summary information and an analysis of the factors that affect the cost of water supply, and Volume II contains the basic data from each of the selected utilities.

SECTION 3

CONCLUSIONS

In Volume I of this report, five of 12 utilities have been selected for in-depth analysis. System and cost data have been summarized for each utility individually, and some individual comparisons have been made. These data indicate a general increasing trend in demand for revenue-producing water, increasing labor wage rates, and the other operating and capital expenses associated with water supply. The systems evaluations for Kansas City and Cincinnati indicate increasing unit costs with increasing distance from the treatment plant. This analysis implies that there are definite limitations to the efficient size of a water supply system. Using a ratio of unit costs to the Consumer Price Index, however, it is shown that if not for inflation unit costs would have risen less rapidly or perhaps declined over time.

A mathematical model has been developed that relates operating cost to labor wage rate, labor productivity, and revenue-producing water. Other models have been developed to relate capital cost to unit depreciation and revenue-producing water and to demonstrate decreasing returns to distance of transmission. A relationship between interest and depreciation has also been developed.

Finally, the data and associated analyses presented here are used to evaluate the hypothetical impact of the safe Drinking Water Act in 1980. These data show the cost of water will increase by 36% between 1975 and 1980 as a result of normal demand and inflationary pressures. If expensive add-on technology, such as granular activated carbon, is required by the Safe Drinking Water Act, water costs will increase by another 24%.

These data will be useful for planners, designers, and decision makers in planning for the implementation of the Safe Drinking Water Act. Appendix A summarizes the slopes of the various cost curves for each utility and for the average of all utilities, and will provide useful information on the variations in costs associated with each utility.

SECTION 4

DATA ANALYSIS FROM SELECTED WATER UTILITIES

Data from five selected utilities will be analyzed in detail in this section. Each featured utility has some aspect that makes it representative of many other utilities across the country. The Kansas City water system, which will be examined first, is relatively simple and provides some useful insights into the cost of distributing water; it represents a no-growth situation.[5] The Cincinnati water supply system is similar to that of Kansas City, but somewhat more complex. A depreciation analysis has been made of Cincinnati's total system.[6] The Dallas, Texas, water utility is supplying water to a rapidly growing area. Its distribution system is complex, including reservoirs and three treatment plants.[7] Fairfax County Water Authority is a regional water utility of recent origin that illustrates the economies of scale that might result from a group of utilities banding together. The Elizabethtown Water Company is a private utility that demonstrates some of the problems associated with private sector water supplies.

KANSAS CITY, MISSOURI

The Kansas City Water Utility serves its metropolitan area with a population of nearly 500,000 and a land area of 400 square miles. The utility's total service population is approximately 600,000, which includes several smaller surrounding cities. The total population of the metropolitan area is greater than 1 million.

Figure 2 shows the total revenue-producing water pumped by the utility during the 10 years of analysis. Note that the abscissa is in integer number of years. This was done to facilitate later comparisons. Year 1 is 1965 and year 10 is 1974. Table 3 contains the cost data collected during the 10-year period. The analysis for unit costs has been based on revenue-producing water rather than on total water pumped. Because the utility draws its water from a free-flowing river and little pumping is required, acquisition costs are small. It can be seen that the total operating cost of water supply has increased during the period of analysis from $6.7 million to $11.6 million. Support services has increased from $1.8 million to $3.8 million (Figure 3). The unit operating cost of water supply increased from $176.56/million gallons (mil gal) to $331.45/mil gal, with the greatest increase occurring under support services -- from $70.11/mil gal to $140.99/mil gal (Figure 4). Figure 5 shows that as a percent of total cost, support services increased from 39.71% to 42.54%.

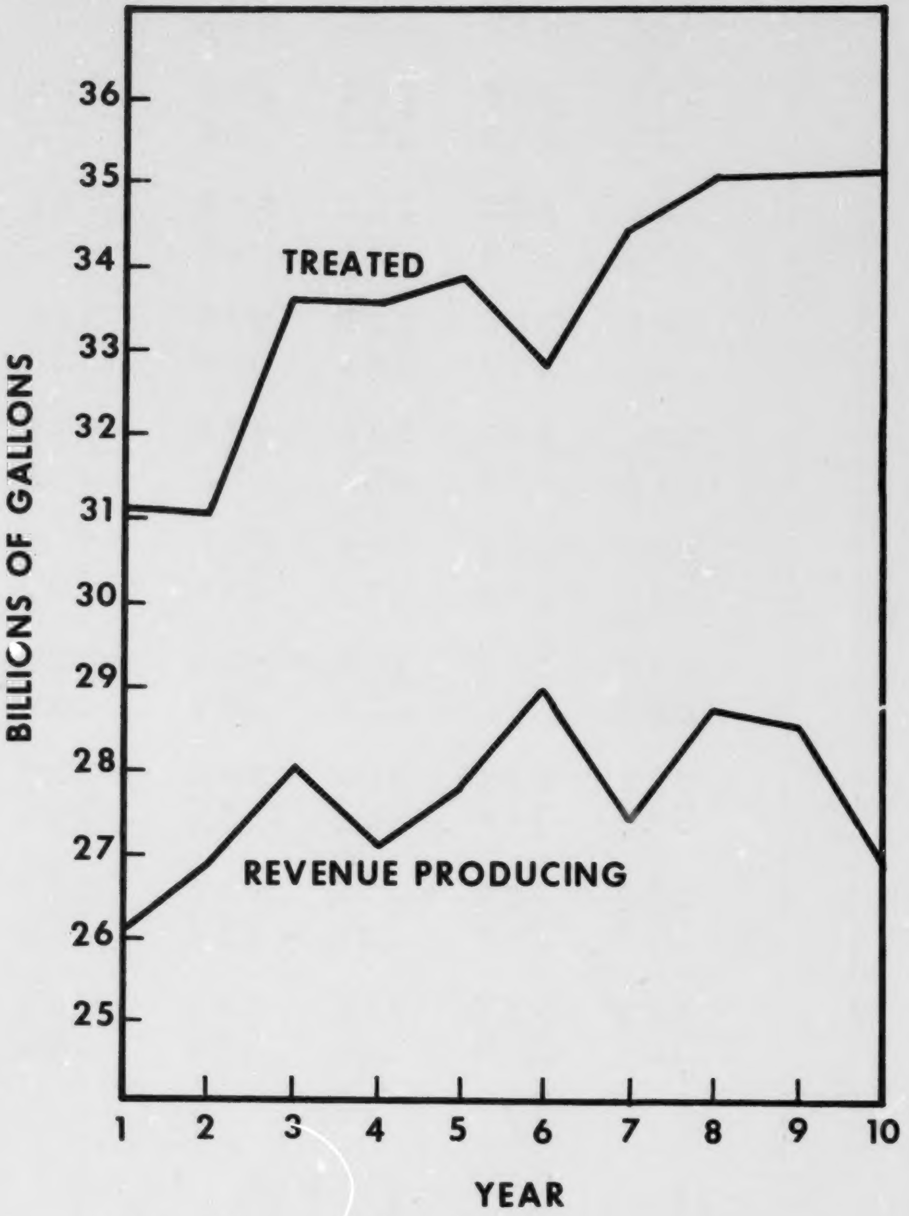

FIG. 2 TREATED AND REVENUE PRODUCING WATER FOR KANSAS CITY WATER UTILITY

TABLE 3. OPERATING AND CAPITAL COSTS FOR KANSAS CITY, MISSOURI

Item	Year									
	1	2	3	4	5	6	7	8	9	10
OPERATING COSTS:										
Support services:										
$, in millions	1.837	2.062	2.145	2.651	3.148	3.417	3.566	3.580	3.815	3.786
% of total	39.71	41.63	40.10	43.96	45.74	44.92	44.78	43.24	43.78	42.54
$/mil gal	70.11	76.43	76.43	97.68	113.09	118.29	129.99	124.61	135.43	140.99
Acquisition:										
$, in millions	0.233	0.230	0.251	0.277	0.307	0.318	0.337	0.350	0.365	0.374
% of total	5.04	4.64	4.69	4.59	4.46	4.16	4.23	4.23	4.19	4.20
$/mil gal	8.90	8.52	8.94	10.20	11.03	10.97	12.28	12.19	12.96	13.92
Treatment:										
$, in millions	1.018	1.086	1.195	1.196	1.291	1.535	1.562	1.716	1.883	1.999
% of total	22.00	21.92	22.33	19.84	18.74	19.70	19.62	20.73	21.61	22.45
$/mil gal	36.84	40.25	42.57	44.08	46.33	51.87	56.96	59.73	66.84	74.42
Power and pumping:										
$, in millions	0.955	0.946	1.030	1.138	1.260	1.306	1.384	1.438	1.500	1.537
% of total	20.64	19.10	19.26	18.87	18.31	17.09	17.38	17.38	17.21	17.27
$/mil gal	36.44	35.07	36.71	41.93	45.27	45.05	50.45	50.09	53.24	57.24
Transmission and distribution:										
$, in millions	0.584	0.629	0.729	0.769	0.878	1.068	1.113	1.196	1.152	1.205
% of total	12.61	12.71	13.63	12.75	12.76	14.03	13.98	14.44	13.21	13.54
$/mil gal	22.27	23.33	25.98	28.32	31.55	36.95	40.58	41.62	40.88	44.87
Total operating costs:										
$, in millions	4.627	4.954	5.349	6.031	6.883	7.644	7.962	8.280	8.716	8.902
$/mil gal	176.56	183.60	190.61	222.20	247.23	263.61	290.27	288.18	309.37	331.45

TABLE 3 (Continued). OPERATING AND CAPITAL COSTS FOR KANSAS CITY, MISSOURI

Item	Year									
	1	2	3	4	5	6	7	8	9	10
CAPITAL COSTS:										
Depreciation ($, in millions)	1.009	1.043	1.056	1.065	1.098	1.118	1.157	1.202	1.264	1.315
Interest ($, in millions)	1.064	1.067	0.981	0.940	1.061	1.207	1.519	1.456	1.407	1.351
Total capital costs ($, in millions)	2.073	2.110	2.037	2.006	2.159	2.325	2.676	2.658	2.671	2.666
TOTAL OPERATING AND CAPITAL COSTS:										
$, in millions	6.700	7.064	7.386	8.037	9.042	9.968	10.639	10.938	11.387	11.567
$/mil gal	255.65	241.15	263.21	296.10	324.84	345.03	387.82	380.71	404.18	430.74

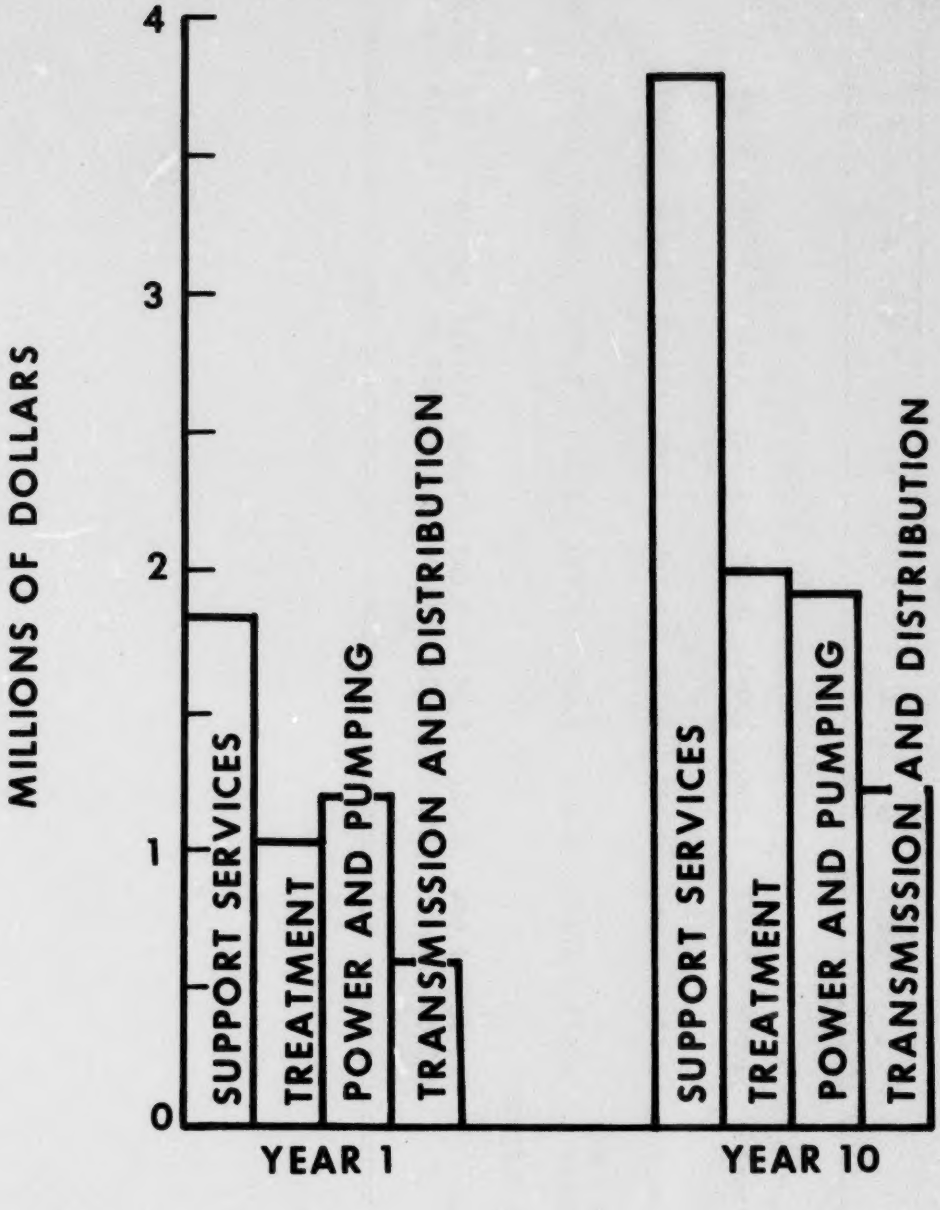

FIG. 3 OPERATING COSTS FOR KANSAS CITY WATER UTILITY

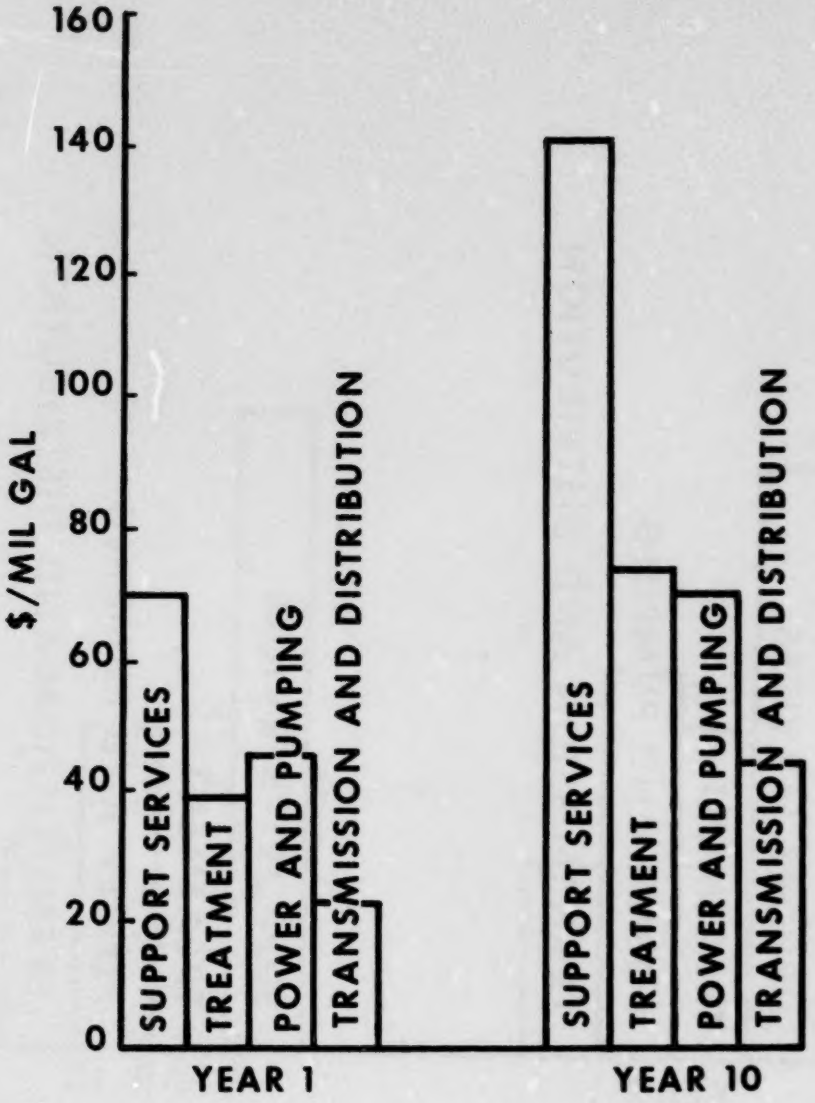

FIG. 4 OPERATING COSTS IN $/MIL GAL FOR KANSAS CITY WATER UTILITY

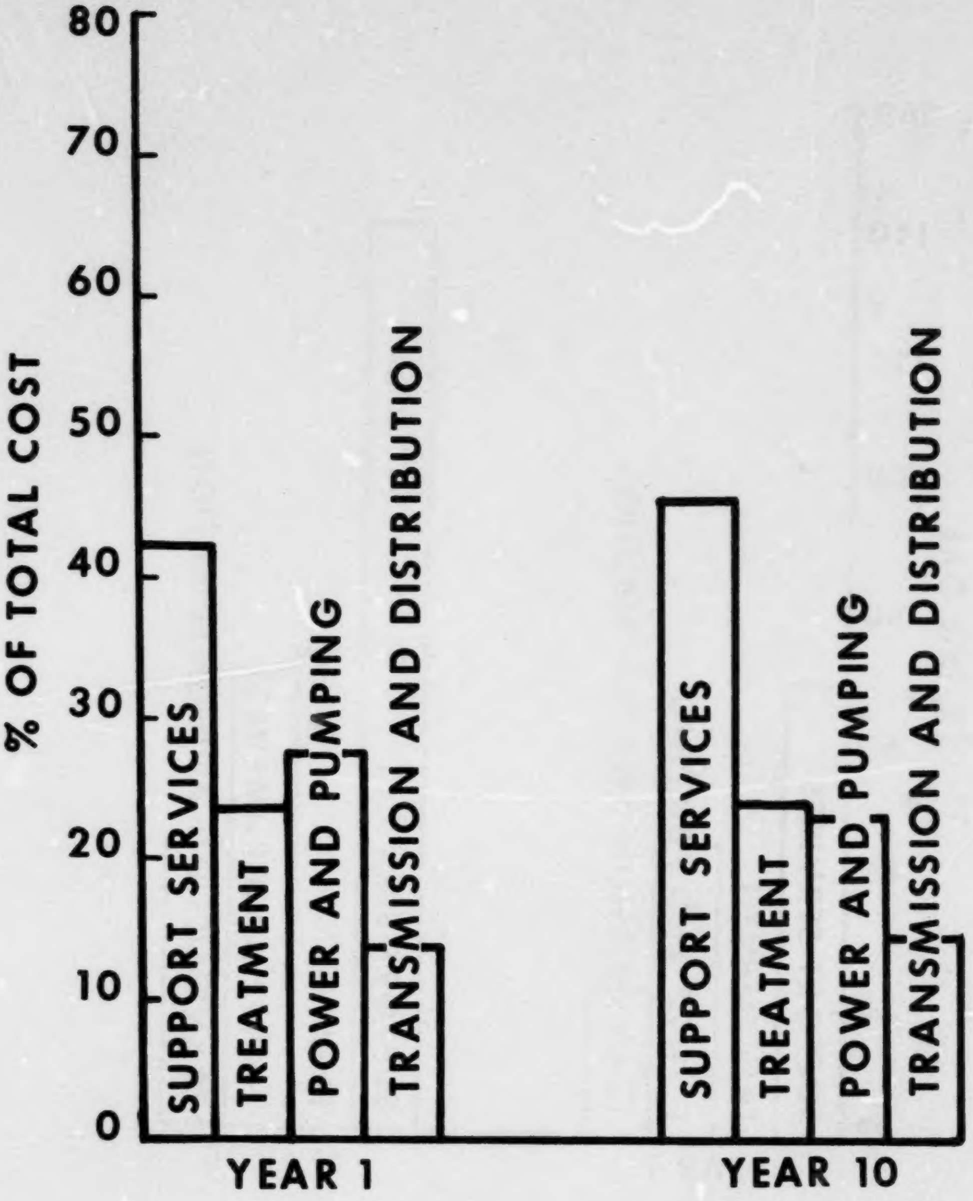

FIG. 5 OPERATING COSTS AS PERCENT OF TOTAL COST FOR KANSAS CITY WATER UTILITY

Figure 6 shows the shift in operating expenditures relative to capital expenditures. The utility is becoming less capital intensive on a historical cost basis over the 10-year period.

Figure 7 shows the total operating and capital expenditures over time. The slope of the operating cost curve is much steeper than capital cost.

Figures 8 and 9 show total and unit costs, respectively. Each expenditure category has been corrected by the CPI assuming 1965 as the base year. The slopes of the total and unit costs are much flatter than for the historical costs. Corrected unit costs have increased slightly over time.

The data presented in the previous section can be used to develop insights into the ways that the cost of water varies throughout the distribution system.[5,8] Figure 10 is a schematic diagram of the utility service area. Water is taken into the system at the intake (denoted by I in the diagram), passed through the Treatment plant (T), and pumped north through a high head system (P_N) and south by a low head system (P_S). To the south, the water passed through a tunnel/flow line to a set of reservoirs and repumping stations (RPS_1 and RPS_2) and then to another set of reservoirs and repumping stations (RPS_3 and RPS_4). Stations RPS_1 and RPS_2 serve the distribution area denoted as zone 3 on the schematic diagram, and stations RPS_3 and RPS_4 serve zone 4. The high head pumping station P_N is designed so that it can serve zone 2 directly as well as pump water to the reservoir and pumping station denoted by RPN.

The costs shown in Figure 10 were derived from the current depreciation and operating cost for each component. Once derived, the costs can be divided by the amount of revenue-producing water passing through the facility or transmission line, yielding a cost for that given component in dollars per million gallons ($/mil gal). Transmission costs shown in Table 4 are derived this way. As water moves from one facility to another, the unit costs are added. Table 4 shows the cost per million gallons for water transmitted from T to RSP_1 and RSP_2 is $9.12/mil gal.

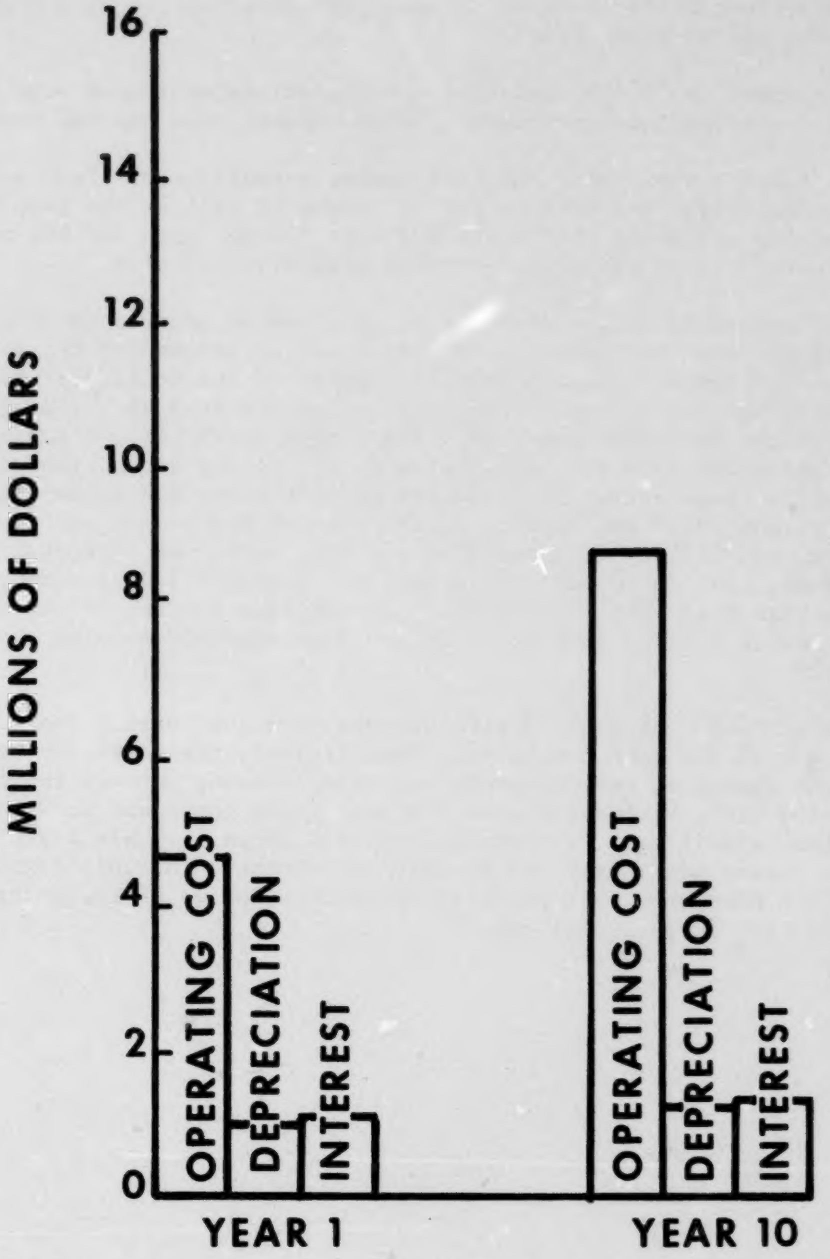

FIG. 6 CAPITAL AND OPERATING COSTS FOR KANSAS CITY WATER UTILITY

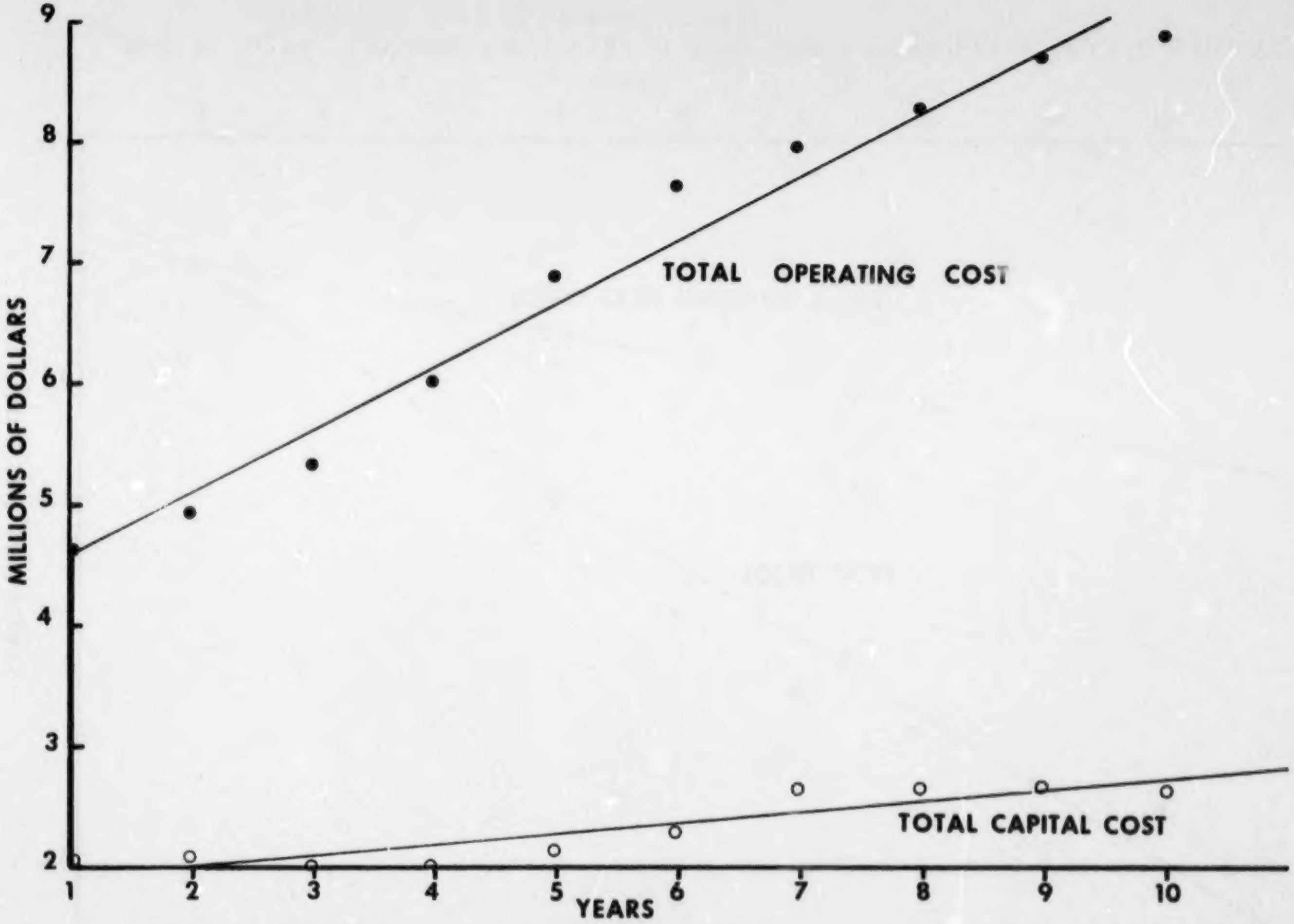

FIG 7 OPERATING AND CAPITAL EXPENDITURES FOR KANSAS CITY WATER UTILITY

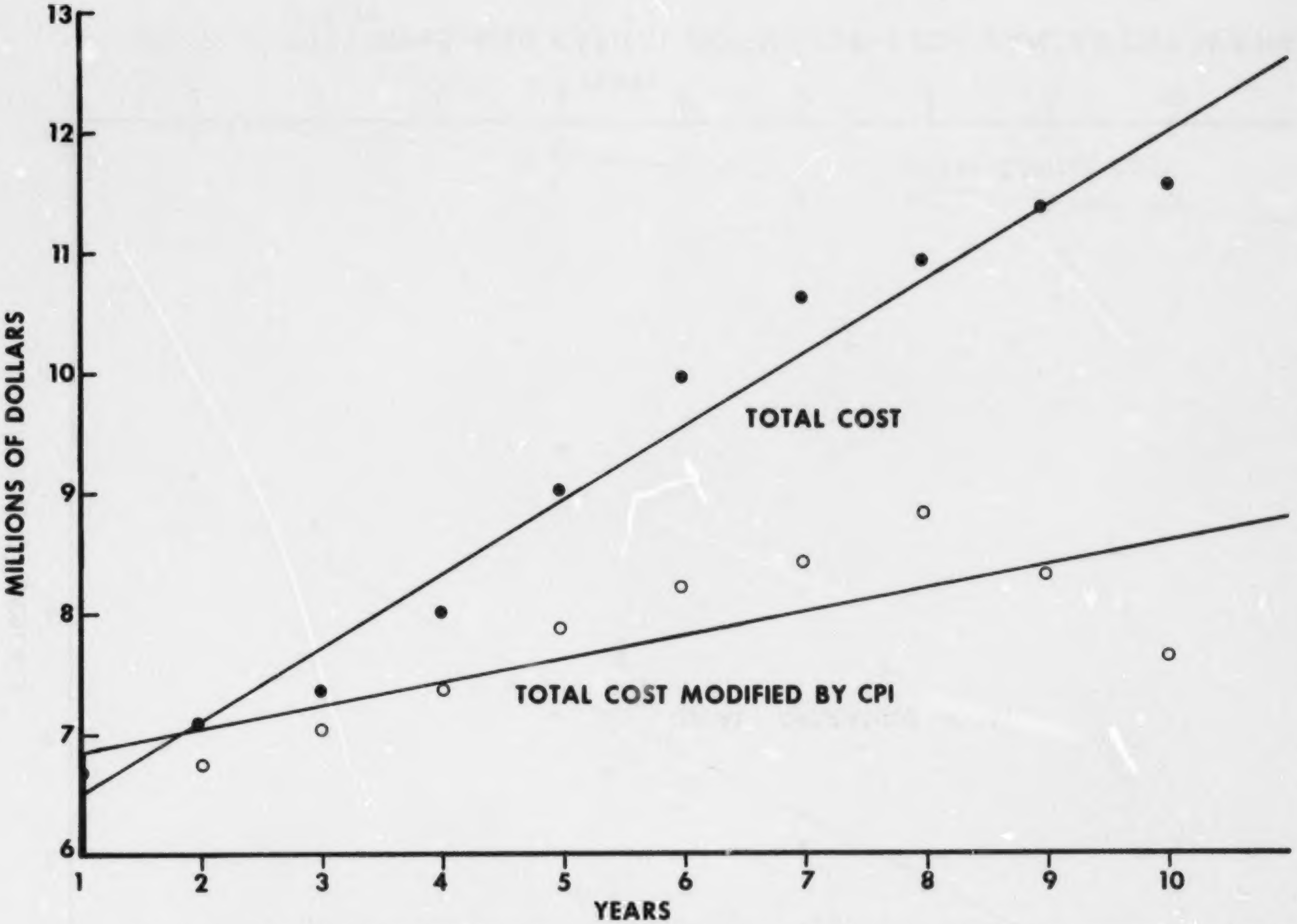

FIG. 8 TOTAL EXPENDITURES VERSUS TIME FOR KANSAS CITY WATER UTILITY: HISTORICAL AND MODIFIED COSTS

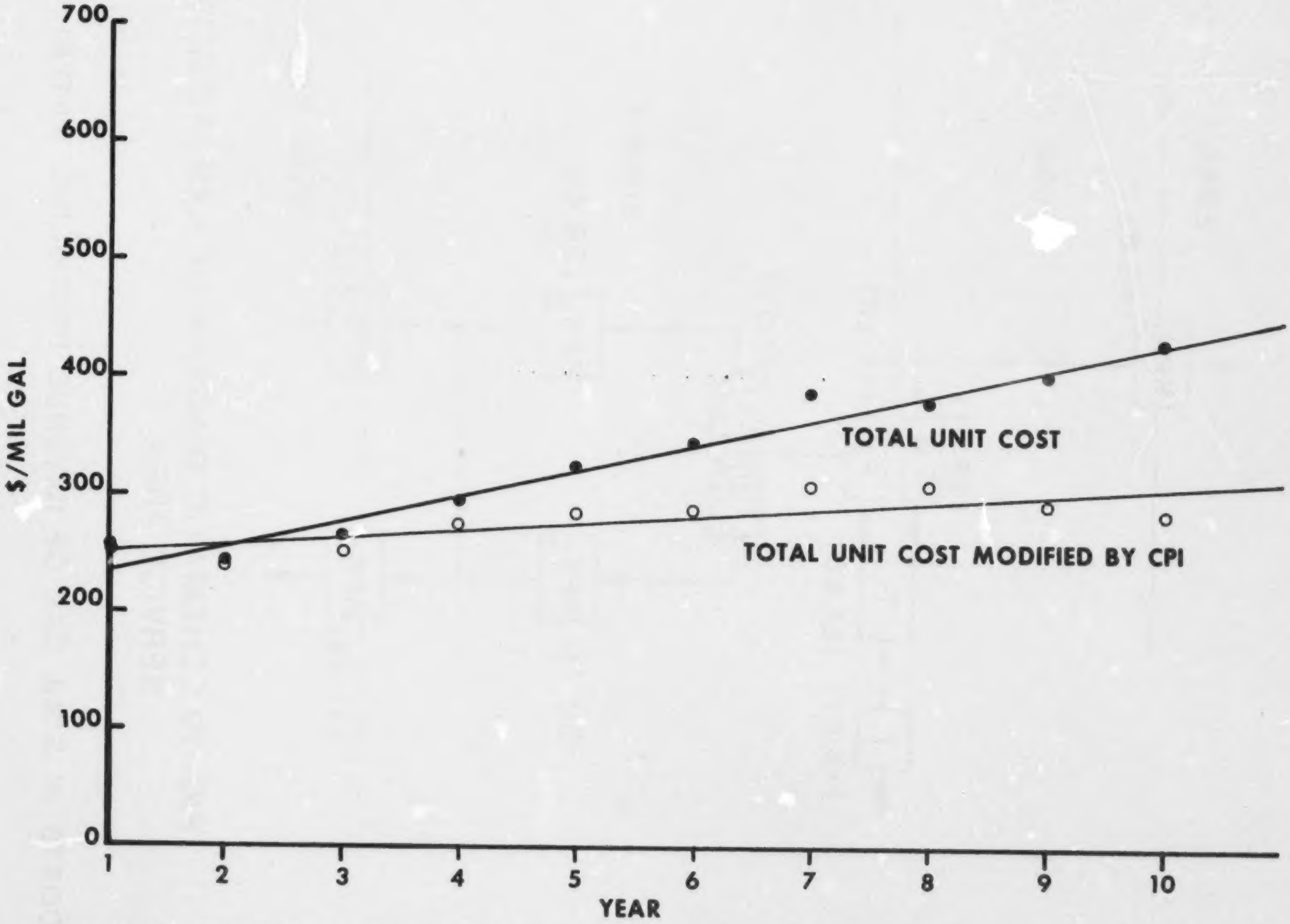

FIGURE 9 UNIT COSTS FOR KANSAS CITY WATER UTILITY: HISTORICAL AND MODIFIED

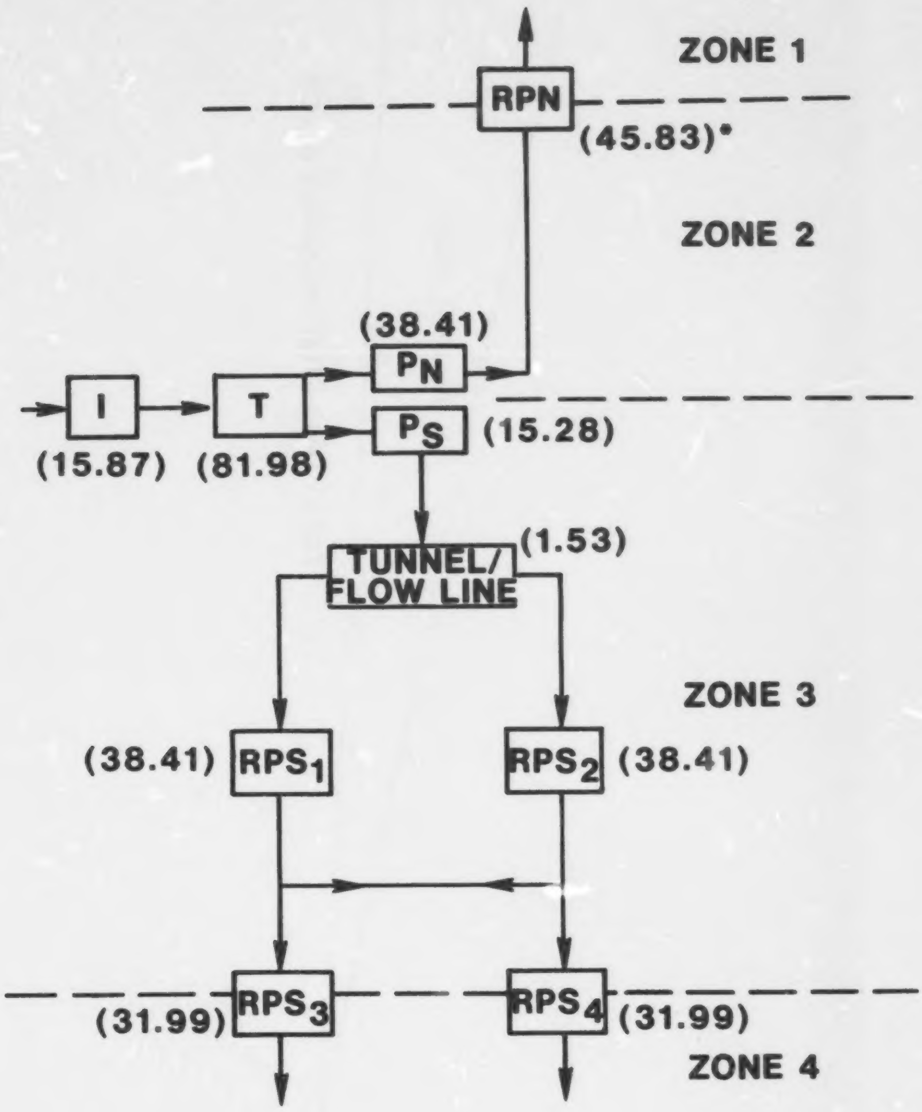
ZONE 1
RPN
(45.83)*
ZONE 2
(38.41)
P_N
I
T
P_S
(15.28)
(15.87)
(81.98)
TUNNEL/ FLOW LINE
(1.53)
ZONE 3
(38.41)
RPS_1
RPS_2
(38.41)
RPS_3
(31.99)
RPS_4
(31.99)
ZONE 4

FIG. 10 SCHEMATIC DIAGRAM OF KANSAS CITY SERVICE AREA

*(COSTS IN $/MIL GAL OF REVENUE PRODUCING WATER)

TABLE 4. TRANSMISSION COSTS BETWEEN FACILITIES IN SERVICE AREA ($/mil gal)

From	To			
	P_N	RPN	RPS_1 and RPS_2	RPS_3 and RPS_4
T	10.69	---	9.12	---
P_N	---	13.21	---	---
RPS_1 and RPS_2	---	---	---	13.27

Each zone represents a consumer service area and a demand point for delivered water. For purposes of this analysis, an attempt was made to discriminate between the water transmitted from one distribution area to another.

Using data for the most recent year, the capital and operating costs for each facility were computed as shown in Figure 10. When a unit of water moves through one facility to another distribution zone, the unit costs of moving the water from one facility to another are added, thereby creating the unit costs for distribution interest, and overhead to yield a total average unit cost to serve each zone.

Distribution costs are obtained by dividing the total operating and capital (depreciation) costs associated with the distribution system by the total revenue-producing water, and the assumption is made that the cost of a distribution system is essentially constant throughout the system.

Costs for interest and support services are calculated in this same manner. Some argument could be made that the interest cost should be proportional to the capital cost for a facility and that support services costs will vary, depending on consumption. However, the burden and difficulty of making these allocations proved to beyond the scope of the study.

To illustrate how the costs in Table 5 are obtained, we can work through the following example. Incremental costs for zone 3 are obtained by adding the costs in $/mil gal for the intake facility, the treatment plant, the facility costs for the pumping station (P_S). the facility costs for the

TABLE 5. INCREMENTAL COST FOR SERVICE ZONES
($/mil gal)

Zone number	Incremental cost	Distribution costs	Interest costs	Support services costs	Total costs	Metered consumption (mil gal/yr)	Revenue recovered
1	205.40	61.05	50.32	144.52	461.33	458	211,289
2	146.36	61.05	50.32	144.52	402.25	2,072	833,462
3	163.19	61.05	50.32	144.52	419.43	17,383	7,290,952
4	208.45	61.05	50.32	144.52	464.34	6,942	3,223,448

tunnel/flow line, the facility costs for RPS_1 and RPS_2, and the transmission costs from T to RPS_1 and RPS_2. To this incremental cost we add the constant distribution cost, interest cost, and support services cost, yielding a total of $419.43/mil gal. Table 5 gives the cost for each zone in $/mil gal and the metered consumption in each zone (mil gal/year). The last column in Table 5 is revenue generated from each zone. The total revenue calculated in this manner is close to the revenue required to cover costs for the latest water year (Table 3).

The costs for each zone, plotted in Figure 11, are described by a step function. As water is pumped and moved to a new zone, the costs take a definable jump. This step function suggests that diseconomies of scale may result as the network for delivering water increases in size. Dajani and Gemmell confirm this observation in their study of the cost of treatment and transportation systems for wastewater.[5] They believe that a number of smaller and simpler networks may be more economical than a large enveloping system, and that a multiple plant treatment system may be called for. Following this logic, we might hypothesize a situation in which an extension of the service area beyond zone 1 (to the north) is contemplated, thereby creating a new zone, 1a. Figure 12 shows the costs for zones 1 and 2 north of the treatment plant and the assumed cost for the new zone 1a, given that additional pumping and storage facilities and possibly expanded plant capacity are required to service the area. This cost curve is represented by a dotted line and assumes that the additional cost to serve zone 1a is approximately $32/mil gal.

If the option of building another plant were available (and in this study area it is), and if the plant could be operated in such a way as to achieve reasonable economies of scale, then the cost curve for zone 1a might look like the solid line in Figure 12. In this case, the cost savings resulting from the new plant's construction would be represented by the area formed by the dotted and solid lines in zone 1a, as shown in Figure 12.

The step functions that represent the cost curves are only approximations to the actual costs. However, the curves serve a useful purpose for approximating the costs to a given service zone, and they illustrate the difference in costs as a function of distance for transporting water to the consumer's tap.

Because of the simplicity of the Kansas City distribution system (one treatment plant), it represents an ideal case study area for relating the cost of water supply to distance transported.

CINCINNATI WATER WORKS

The Cincinnati Water Works' service area lies almost entirely within Hamilton County, Ohio, with fringe extensions into three adjoining counties. Although for the most part they are surrounded by the Cincinnati Water Works service area, a number of communities maintain their own systems. Emergency service is provided to most of them, but as long as their source of supply can be maintained, most of the communities will not change their present status.

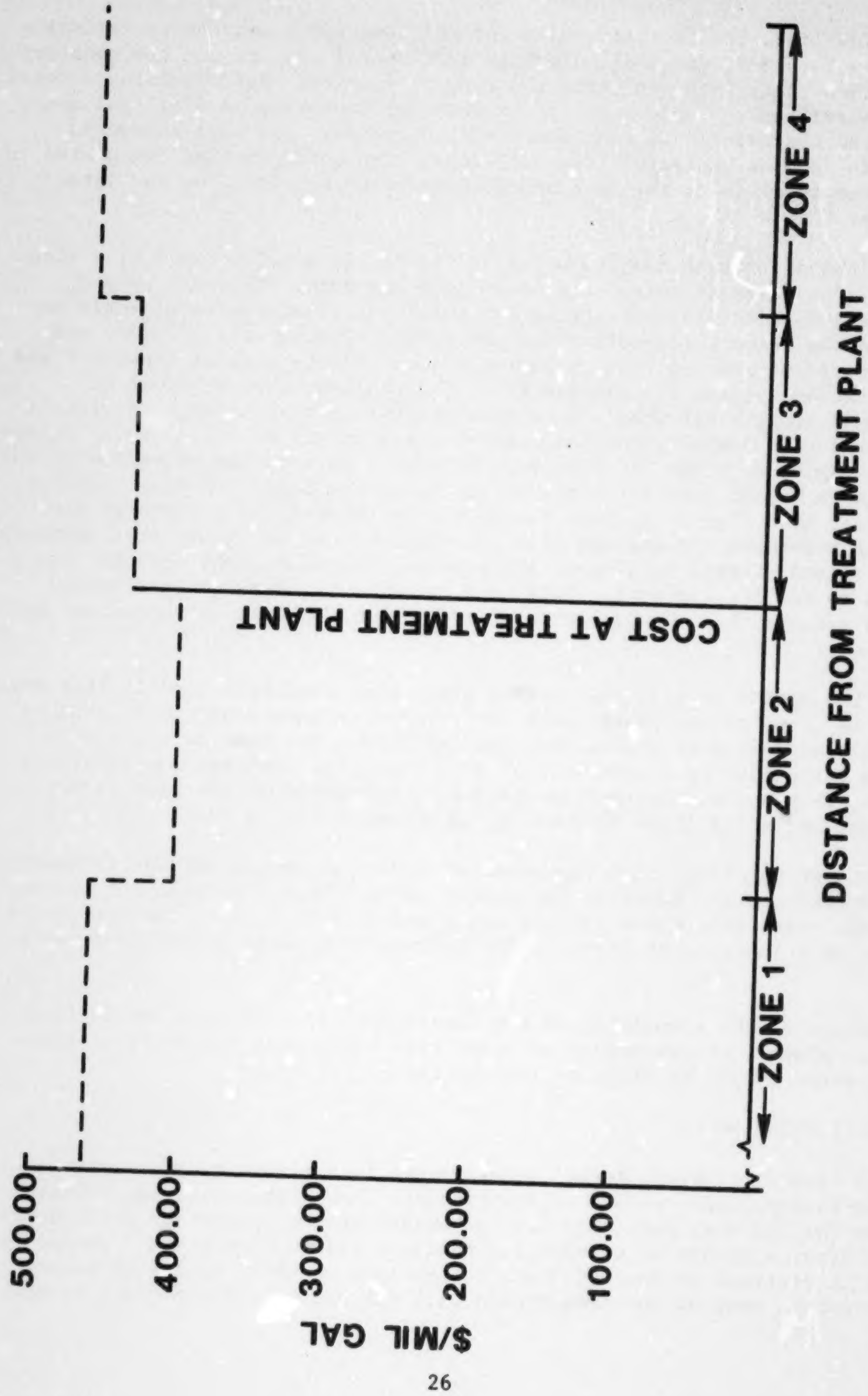

FIG. 11 COSTS BY SERVICE ZONES

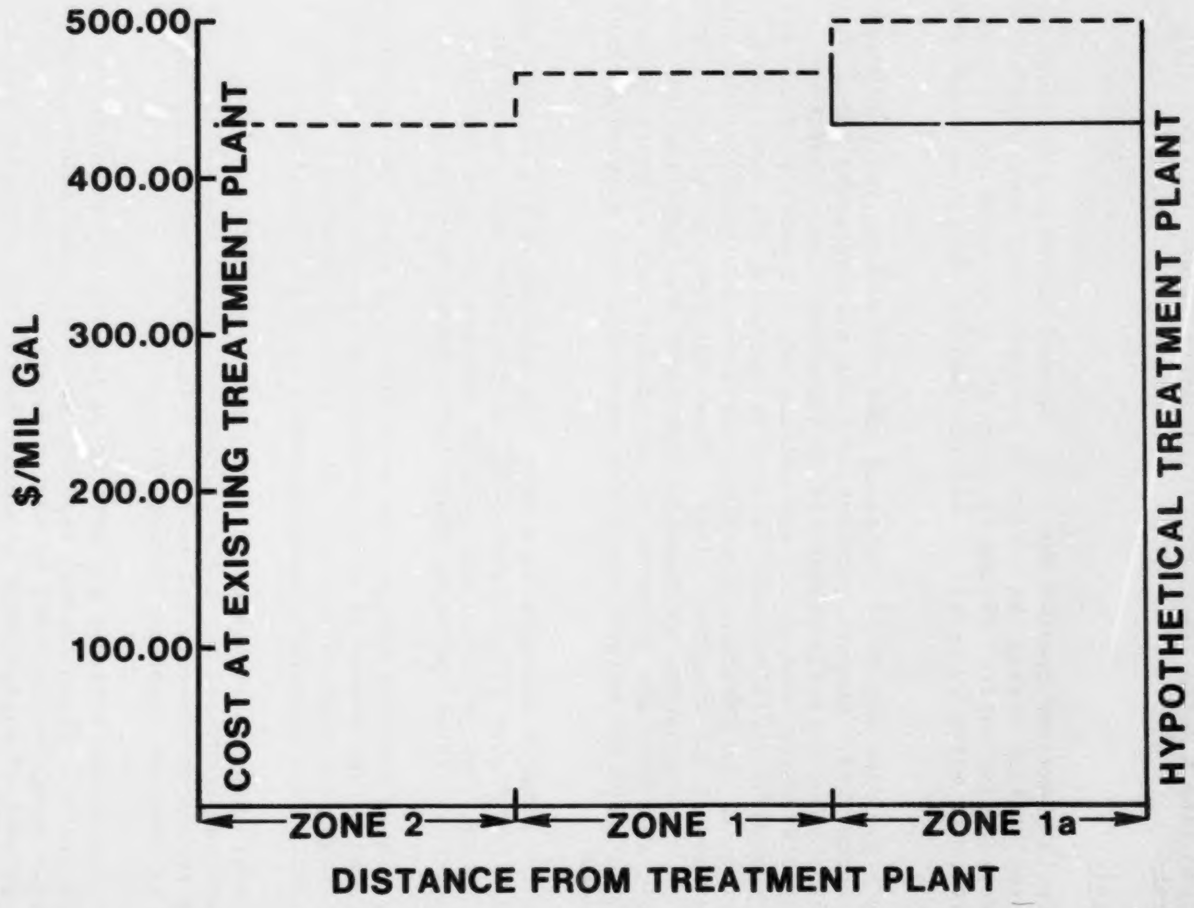

FIG. 12 COST IN EXISTING NORTHERN SERVICE ZONES PLUS HYPOTHETICAL ZONE

The current source of supply is the Ohio River. Water is pumped from the river to two presettling reservoirs on a municipal golf course near the river, and is then pumped to a single treatment plant with a capacity of 235 million gallons per day (MGD). In 1974 the plant treated an average of 136 MGD. To the north and west, water passes through two gravity tunnels and two pump stations into a large reservoir; it is then repumped into outlying service areas.

Cost Analysis

Figure 13 shows the treated water and metered (revenue-producing) water pumped by the utility during the period of analysis. All cost data are based on revenue-producing water. Figure 13 shows the total water pumped exceeded revenue-producing water by nearly 13 billion gallons during the final year of analysis.

Table 6 contains the total operating cost for each of the previously mentioned categories. Support services includes all operating costs that support but are not directly chargeable to the production of water -- general administration, accounting and collection, and meter reading, for example. Treatment includes costs related to operating the laboratory, labor involved in the treatment function, chemicals for purifying the water, and maintenance of the treatment plant. Power and pumping includes costs related to operating labor, maintenance, and power and pumping water throughout the service area. The transmission and distribution category includes the operating labor and maintenance costs associated with supplying water to the consumer.

Costs for support services have more than doubled in the 10-year period (see Table 6 and Figure 14). Although all of the other cost categories increased during this period, their rate of increase was less than that of support services. Total operating costs increased by about 65%.

Table 6 also contains the average unit operating costs for each major category based on the number of revenue-producing gallons pumped in a given year. As shown, all cost categories ($/mil gal) increased by a factor of less than two. Unit operating costs increased by about 40% (Figure 15).

Each cost category is presented as a percent of total operating cost. Support services accounted for a significant portion of the utility's budget, increasing from approximately 26% to 31.5%. The other cost categories either decreased or remained constant (Figure 16).

Depreciation and interest are defined as the capital expenses for the water works system. These capital expenses remained essentially constant, but operating expenses increased by approximately 65% (Figure 17). Table 6 shows the percent of expenditures allocated to capital decreased from approximately 27% to 22% during the period of analysis.

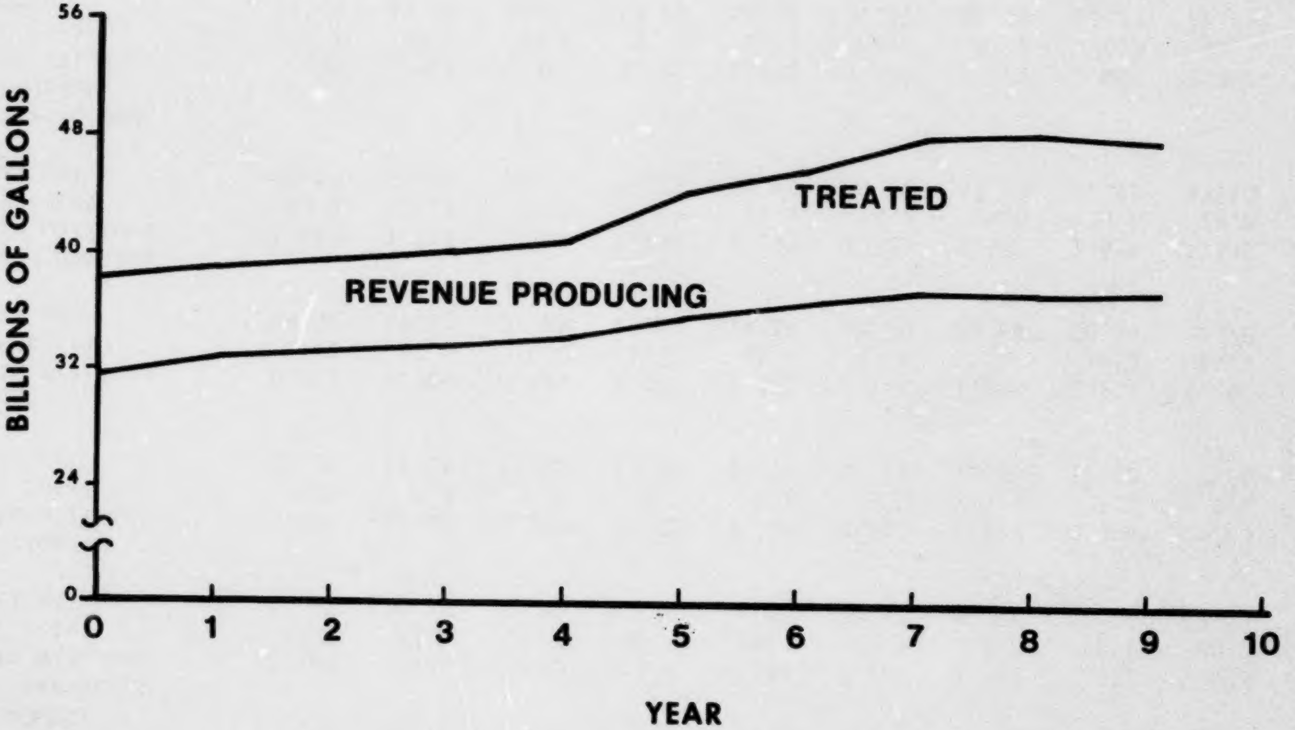

FIG. 13 TREATED AND REVENUE PRODUCING WATER FOR CINCINNATI WATER UTILITY.

TABLE 6. OPERATING AND CAPITAL COSTS FOR CINCINNATI WATER WORKS

Item	Year 1	2	3	4	5	6	7	8	9	10
OPERATING COSTS:										
Support services:										
$, in millions	1.360	1.331	1.413	1.499	1.616	2.109	2.081	2.371	2.633	2.766
% of total	25.6	25.2	25.2	24.9	26.1	29.9	28.6	29.1	30.7	31.5
$/mil gal	42.41	40.24	41.90	43.87	46.55	58.25	56.06	62.20	69.43	72.60
Acquisition:										
$, in millions	0.395	0.369	0.372	0.372	0.380	0.405	0.427	0.496	0.480	0.485
% of total	7.4	7.0	6.7	6.2	6.1	5.8	5.9	6.1	5.6	5.5
$/mil gal	12.25	11.15	11.10	10.90	10.94	11.19	11.50	13.02	12.66	12.73
Treatment:										
$, in millions	0.913	0.906	0.934	1.005	1.012	1.041	1.065	1.165	1.240	1.210
% of total	17.2	17.2	16.6	16.7	16.4	14.8	14.6	14.3	14.4	13.8
$/mil gal	28.48	27.42	27.69	29.41	29.14	28.76	28.69	30.54	32.70	31.75
Power and pumping:										
$, in millions	1.086	1.115	1.182	1.256	1.247	1.412	1.382	1.638	1.635	1.667
% of total	20.5	21.1	21.0	20.9	20.2	20.0	19.0	20.0	19.0	19.0
$/mil gal	33.88	33.74	35.07	36.77	35.92	39.01	37.23	42.97	43.10	43.75
Transmission and distribution:										
$, in millions	1.558	1.554	1.711	1.885	1.928	2.084	2.323	2.487	2.606	2.654
% of total	29.3	29.5	30.5	31.3	31.2	29.5	31.9	30.5	30.3	30.2
$/mil gal	48.60	47.00	50.74	55.19	55.52	57.57	62.58	65.23	68.72	69.65
Total operaing costs:										
$, in millions	5.310	5.275	5.615	6.017	6.183	7.051	7.277	8.158	8.595	8.782
$/mil gal	165.62	159.55	166.50	176.14	178.07	194.78	196.06	213.96	226.61	230.48

TABLE 6 (Continued). OPERATING AND CAPITAL COSTS FOR CINCINNATI WATER WORKS

	Year									
	1	2	3	4	5	6	7	8	9	10
CAPITAL COSTS:										
Depreciation ($, in millions)	1.177	1.230	1.422	1.550	1.605	1.634	1.632	1.657	1.699	1.771
Interest ($, in millions)	0.826	0.947	0.927	0.877	0.887	0.887	0.793	0.802	0.711	0.669
Total capital costs ($, in millions)	2.003	2.177	2.349	2.427	2.492	2.521	2.425	2.459	2.410	2.440
TOTAL OPERATING AND CAPITAL COSTS:										
$, in millions	7.314	7.452	7.964	8.444	8.665	9.571	9.702	10.617	11.005	11.223
$/mil gal	228.10	225.41	236.14	247.19	249.56	264.41	261.39	278.45	290.14	294.54

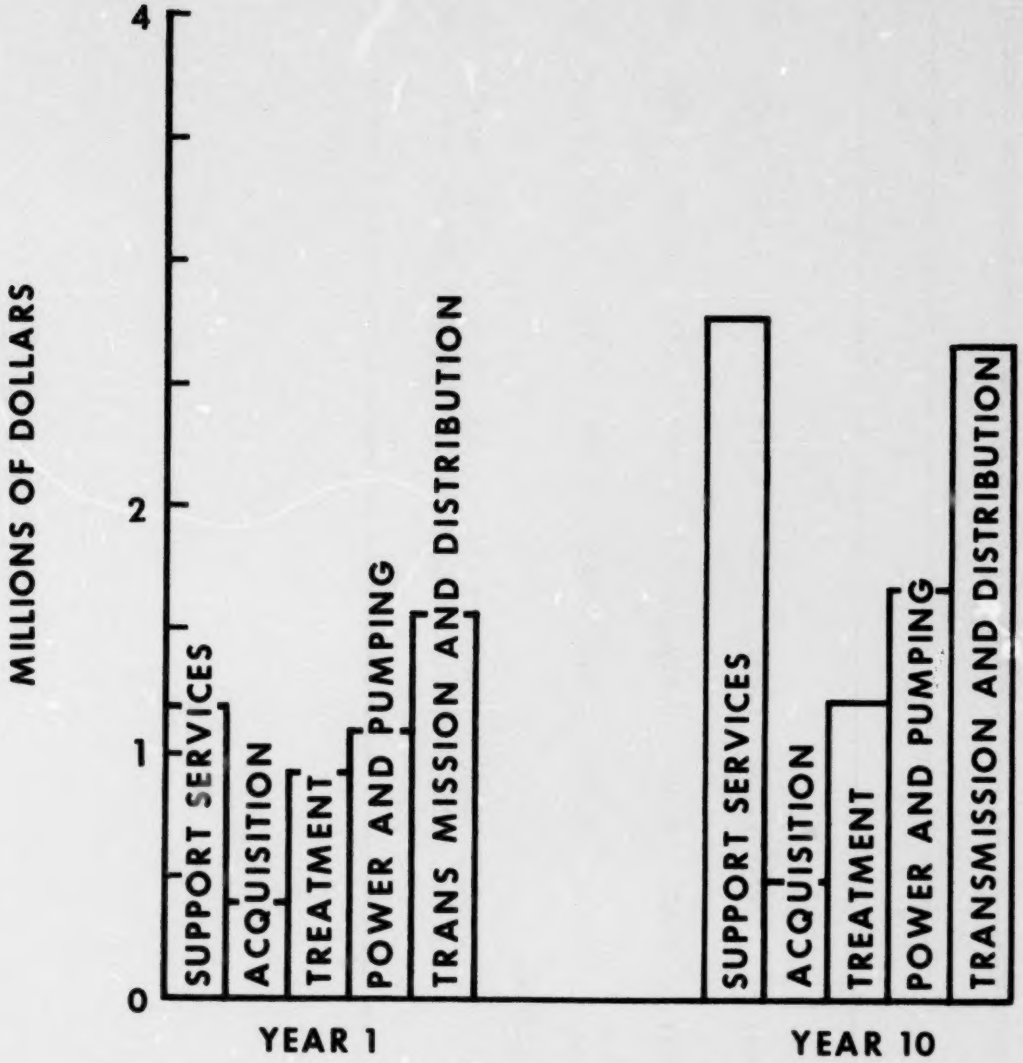

FIG. 14 OPERATING COSTS FOR CINCINNATI WATER WORKS

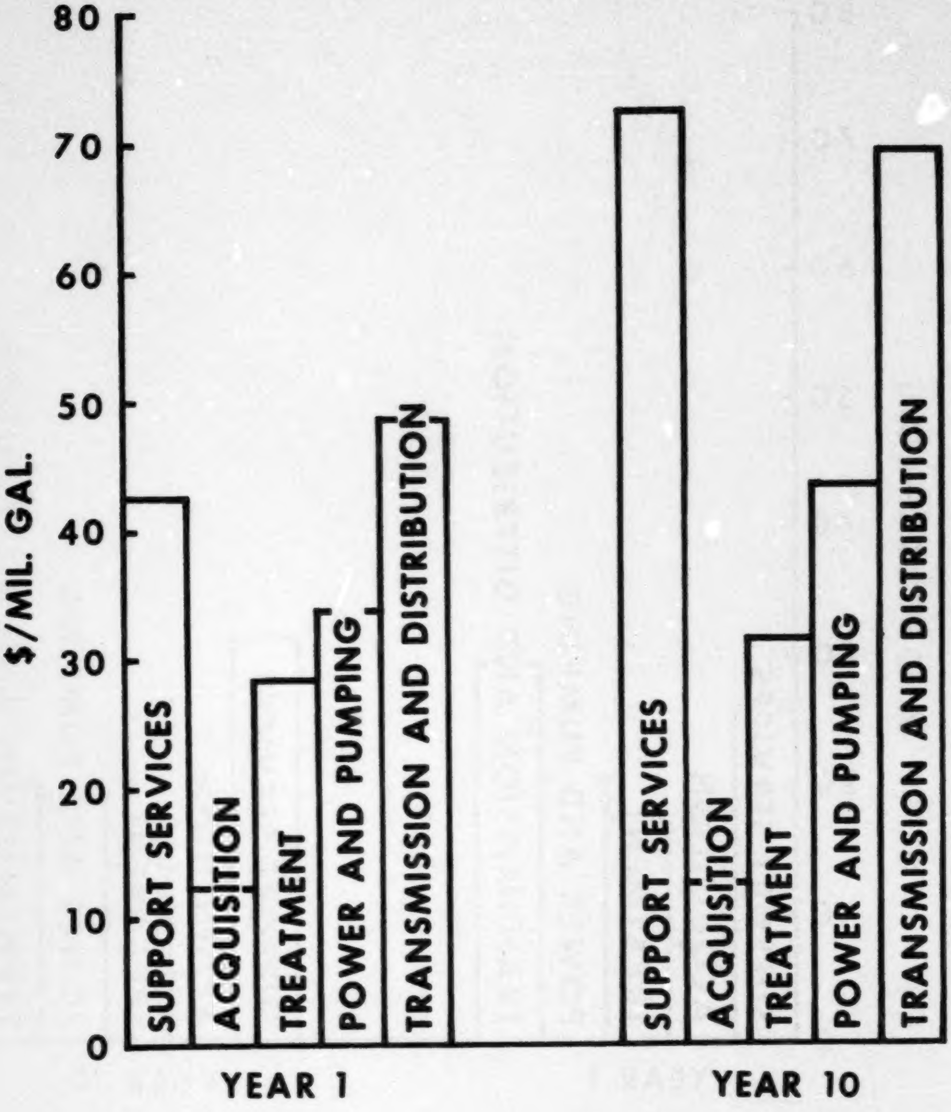

FIG. 15 OPERATING COSTS $/MIL. GAL. FOR CINCINNATI WATER UTILITY

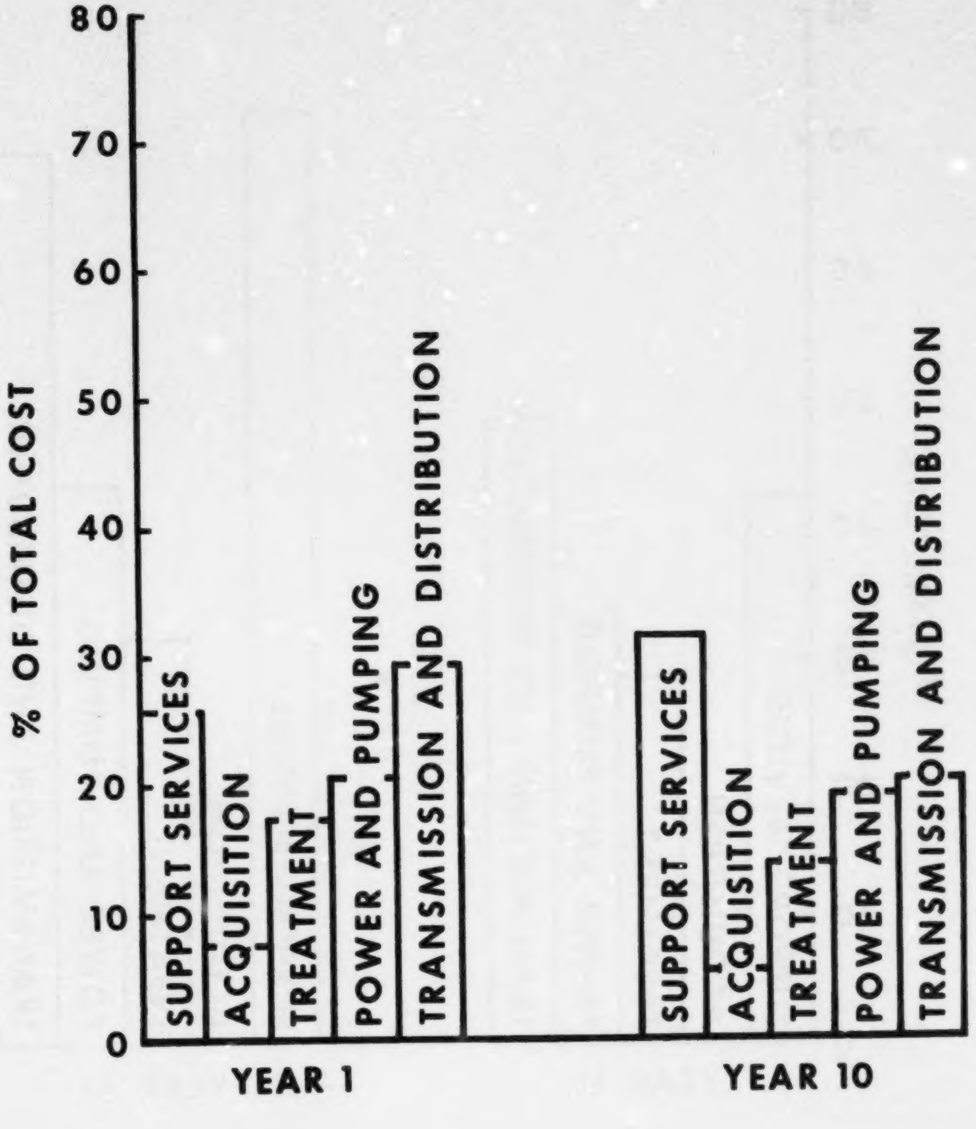

FIG. 16 OPERATING COST AS PERCENT OF TOTAL COST FOR CINCINNATI WATER UTILITY

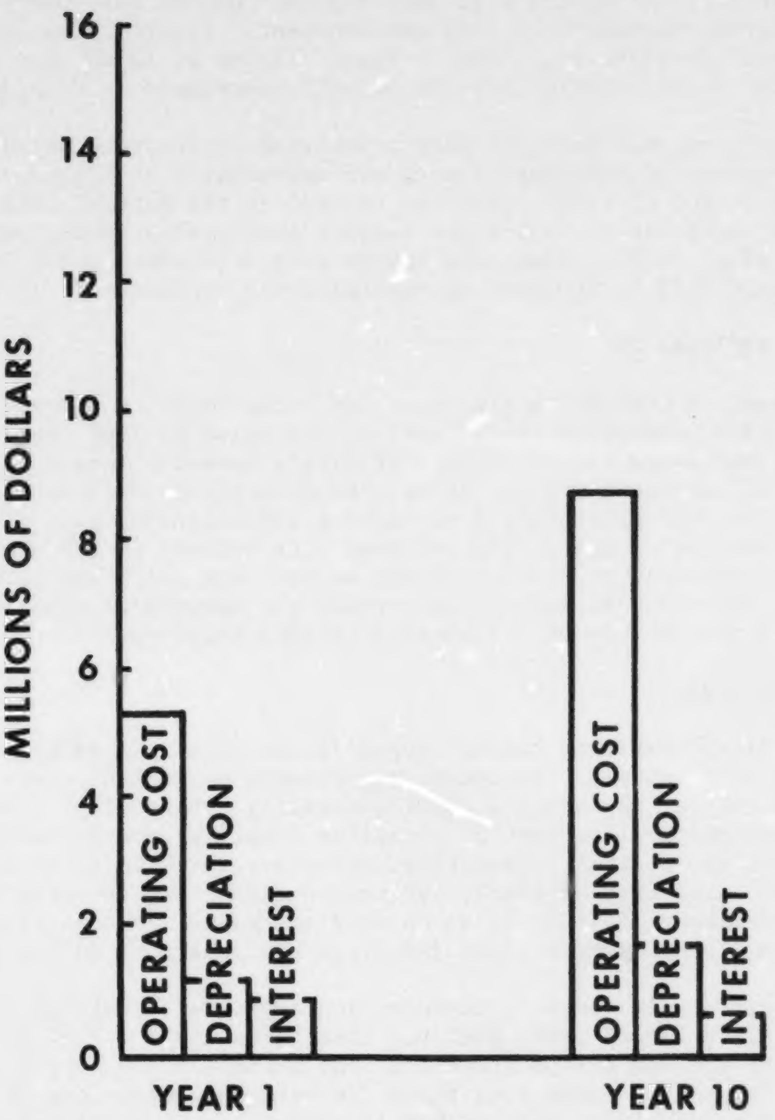

FIG. 17 OPERATING AND CAPITAL COSTS FOR CINCINNATI WATER WORKS

Figure 18 depicts the expenditures for capital and operations and maintenance over the 10-year period. Figure 19 shows the total expenditures (historical and corrected) over the period of analysis. The corrected values have been computed using the CPI, assuming 1965 as the base year. On a corrected basis, expenditures remained constant. Figure 20 shows the actual and corrected expenditures, based on time. Figure 20 shows that the unit cost of water supply (corrected) has actually decreased in Cincinnati.

Operating expenditures are always reported in inflated or current dollars, whereas capital expenditures are depreciated in historical dollars over a long period of time. Problems related to the depreciation of capital will be discussed later. Since the support services category, which is labor intensive, plays an important role in the cost of water supply, labor and manpower costs will be analyzed in the following section.

Labor Cost Analysis --

One means of evaluating the impact of labor costs on operation costs for water supply is to examine the payroll of the water utility (Table 7). Labor costs accounted for 64% of the utility's operating costs in year 1, and the number of man-hours/mil gal of metered consumption decreased by 23%. The bottom line in the table shows a decreasing capital/labor cost ratio. Although economies of scale were achieved with respect to the number of man-hours used to produce water, the effect on cost was nullified by wage increases. The table therefore illustrates the importance of labor in what is typically presumed to be a capital intensive industry.

Depreciation Analysis --

As mentioned earlier, capital expenditures make up a large portion of the cost of water supply. Depreciation reflects historical costs and not the current cost of replacing a capital facility. Historical costs refer to the original construction cost of a capital facility, whereas reproduction costs reflect the capital expenditures necessary to build an identical plant today. Historical cost is exact, but reproduction cost is based on the original investment modified by an appropriate index. A comparison between historical and reproduction costs indicates the impact of inflation.

Using historical costs, a reproduction cost was calculated using the Engineering News Record (ENR) Building Cost Index (1913 = 100) for buildings and equipment and the ENR Construction Cost Index (1903 = 100) for pipes and valves.[10] (A skilled labor cost factor is used to compute the Building Cost Index, and a common labor cost factor is used to compute the Construction Cost Index.) After weighing these capital expenditures with the proper indices, a reproduction cost of $459 million was found for the current plant-in-service, which represents a 311% increase over the historical value. These capital expenditures do not include the capital investment in a new treatment plant (Great Miami), which is operational. Derivation of a reproduction value illustrates the impact of inflation on capital cost and the current worth of capital's contribution to output. The computations discussed in this section are summarized in Table 8.

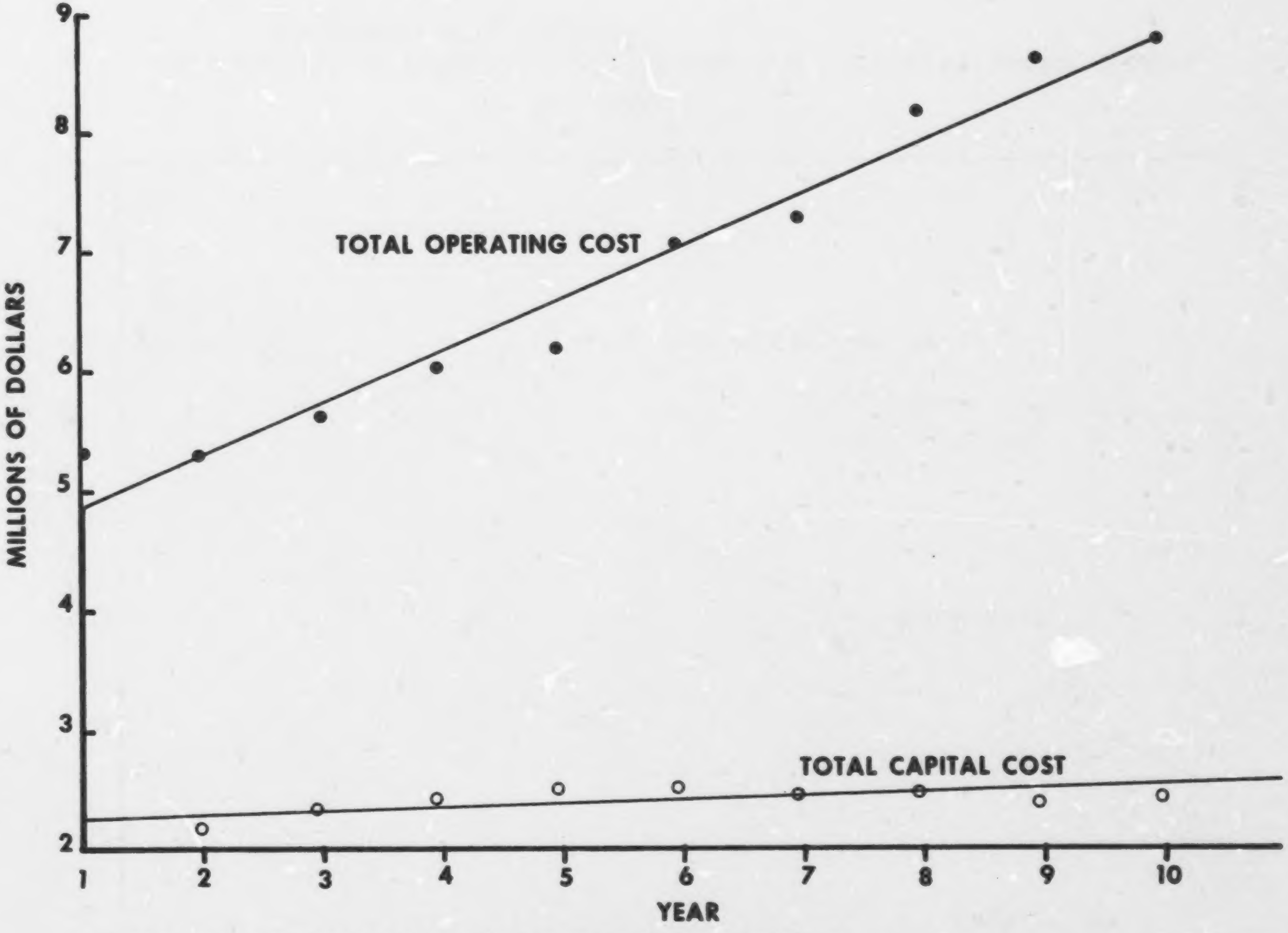

FIG. 18 OPERATING AND CAPITAL EXPENDITURES FOR CINCINNATI WATER WORKS

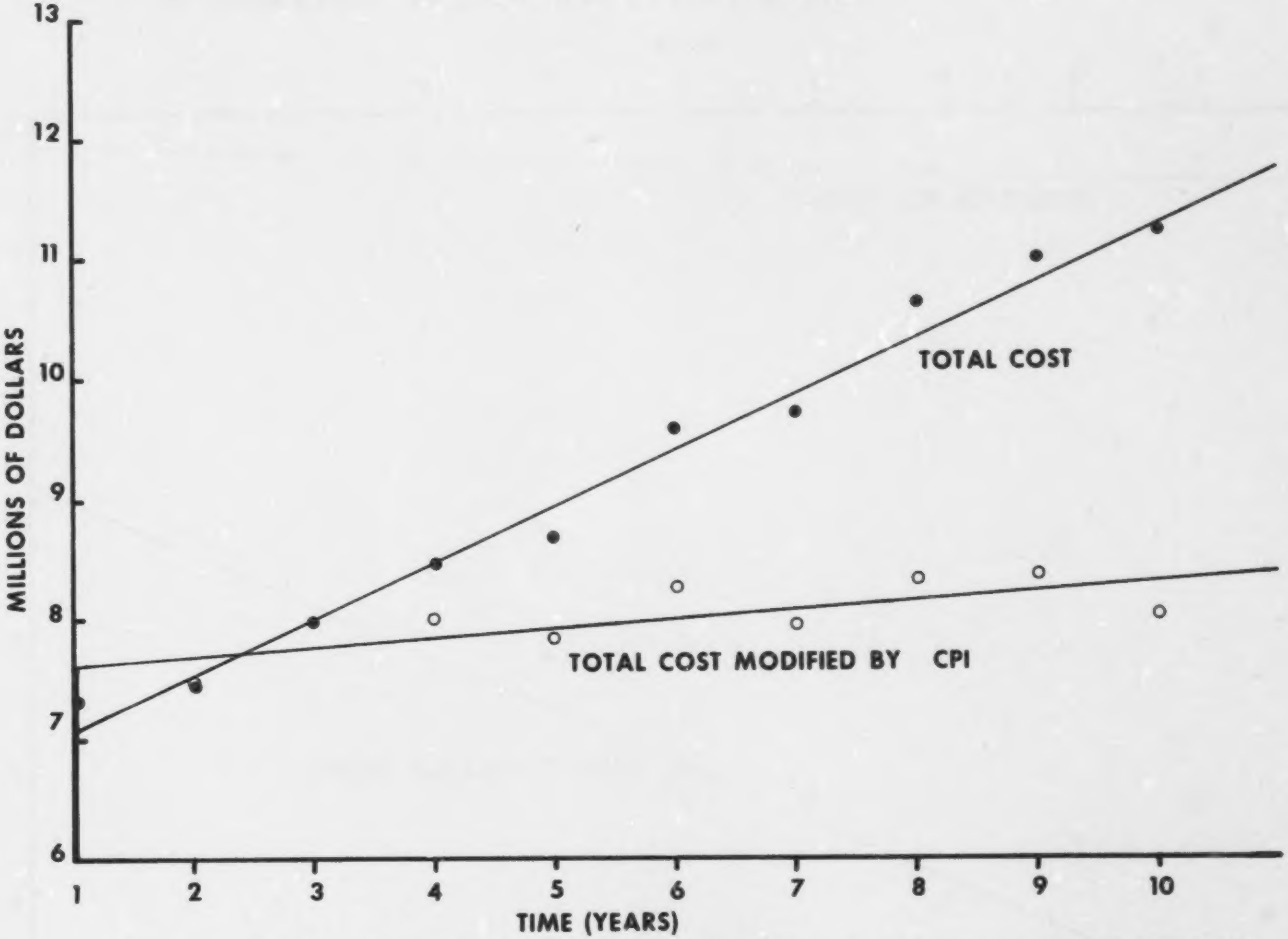

FIG. 19 TOTAL EXPENDITURES VERSUS TIME FOR CINCINNATI WATER WORKS: HISTORICAL AND MODIFIED

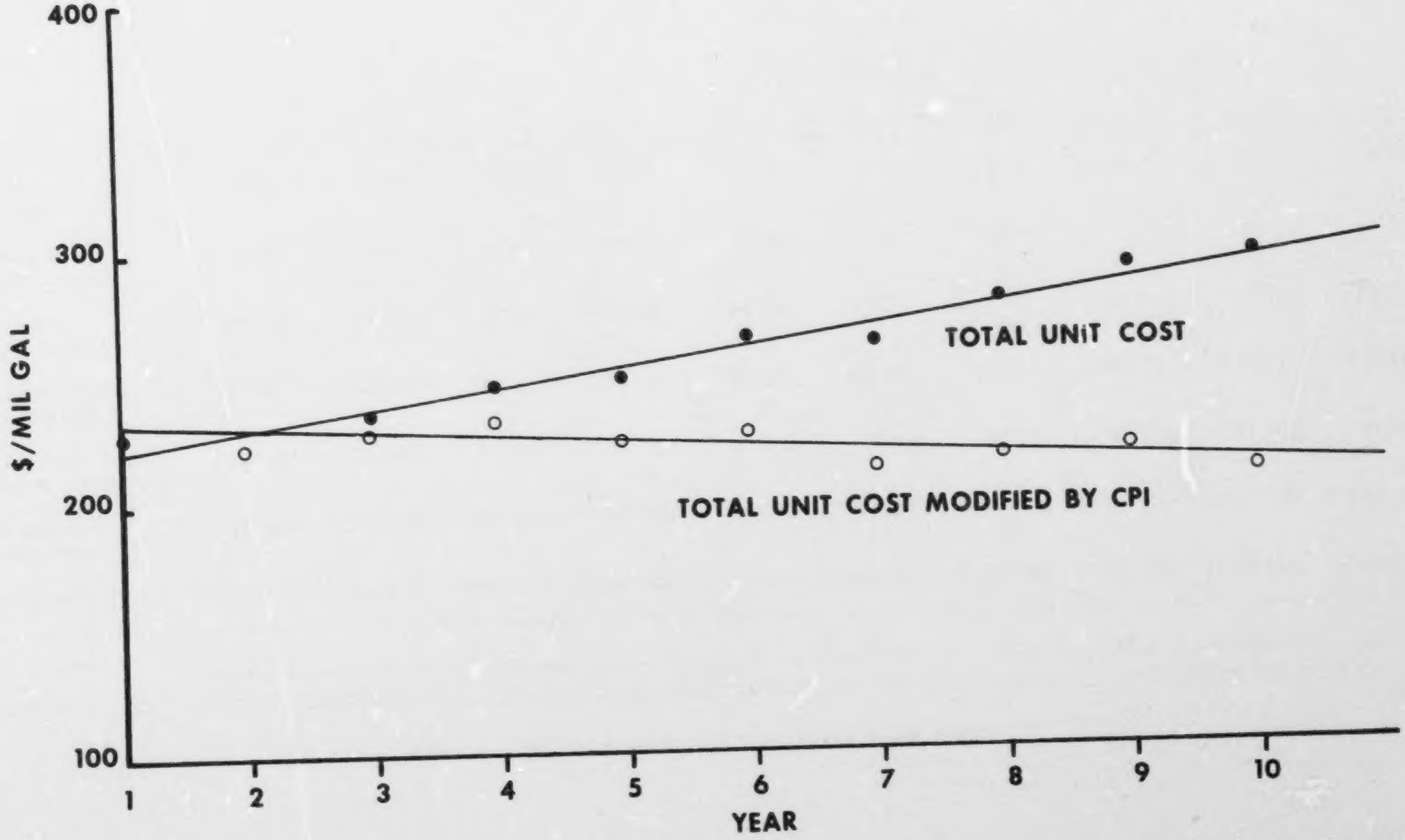

FIG. 20 UNIT COSTS FOR CINCINNATI WATER WORKS: HISTORICAL AND MODIFIED

TABLE 7. MANPOWER COSTS FOR CINCINNATI WATER WORKS

Item	Year									
	1	2	3	4	5	6	7	8	9	10
Total payroll ($)	3,393,575	3,399,082	3,664,567	3,946,864	4,085,948	4,446,863	4,467,360	4,979,657	5,261,055	5,474,585
Total hours on payroll	1,110,032	1,116,220	1,102,892	1,120,980	1,148,588	1,141,448	1,115,744	1,094,229	1,071,476	1,046,824
Metered consumption (mil gal)	32,063	33,061	33,725	34,160	34,722	36,199	37,117	38,128	37,928	38,104
Total payroll ($/mil gal)	105.84	102.81	108.66	115.54	117.68	122.84	120.36	130.60	138.71	143.68
Total hours/ mil gal	34.62	33.76	32.70	32.81	33.08	31.53	30.06	28.70	28.25	27.47
Average cost/ man hour	3.06	3.04	3.32	3.52	3.56	3.89	4.00	4.55	4.91	5.23
Capital/labor cost ratio	0.60	0.64	0.64	0.61	0.61	0.57	0.54	0.49	0.46	0.45

TABLE 8. HISTORICAL AND REPRODUCTION COSTS OF PLANT-IN-SERVICE FOR CINCINNATI WATER WORKS

Capital facility	Historical cost	Reproduction cost (1974 dollars)
Plant	$ 42,649,160	$ 146,981,272
Pipe	54,848,943	296,771,626
Misc. plant*	14,202,213	15,237,389
Total	111,700,315	458,990,286

* Capital expenditures that are not specifically identified.

System Evaluation

Using the cost data for the various functional areas discussed earlier, costs were allocated to specific treatment, transmission, storage, and pumping facilities in the system (Figure 21). A general cost was determined for distribution, interest, and overhead.

The facilities in the schematic diagram (Figure 21) can be related to cost zones, as in Kansas City. For example, the acquisition cost of water from the Ohio River, including depreciation of the facility and operating costs, is $16.70/mil gal. As a unit of water (mil gal) moves through one facility to another, the unit cost of moving water through the first is added to the cost of getting water to the second, thereby creating incremental costs. The facility and transmission costs are added to the costs of distribution, interest, and overhead to yield an average unit cost to serve that area. A service zone represents a customer service area and a demand point for water. For purposes of the distribution cost analysis, an attempt was made to discriminate between the water demanded in a given distribution area and the water transmitted through the area into the next service zone.

To illustrate how cost changes from one service area to another, we can examine the B1 and B2 cost areas (Figure 22). The cost/mil gal for area B1 is composed of acquisition cost ($16.70), treatment cost ($60.26), distribution cost ($50.52), interest cost ($17.57), and overhead cost ($85.22). This yields a total cost of $336.86/mil gal. For the B2 area, the pumping and storage costs ($80.45) and the transmission costs ($60.26) must be added to the B1 costs, which yield $477.60/mil gal. These values are plotted in Figure 23. The costs in each zone are described by a step function. The cost of water pumped from the treatment plant through the B1 is assumed constant; however, as water is repumped into the B2 zone, the costs take a definable jump, yielding a step function.

The step function suggests the possibility that as additional service zones are added to the periphery of the utility service area, the cost functions will continually increase. A comparison of this cost analysis to the prices actually charged in the utility service area is useful. Figure 24 shows all of the cost zones listed in Figure 21 that make up the Cincinnati Water Works service area. Table 9 compares revenues received from the 10 largest users in the service area and the actual cost of service.

The cost column was calculated as shown in Figure 22. Adjusted cost was figured by allocating support services on a service per customer basis. Table 9 shows that in many cases, the major users have not met the cost of supplying water to them.

DALLAS WATER UTILITY

The Dallas Water Utility serves the city of Dallas, which lies within Dallas County in north central Texas.[7] The city has a population of 942,467, and the county's population is 1.5 million, based on the 1970 census. Dallas' annual growth rate of 3.1% has many implications for urban services

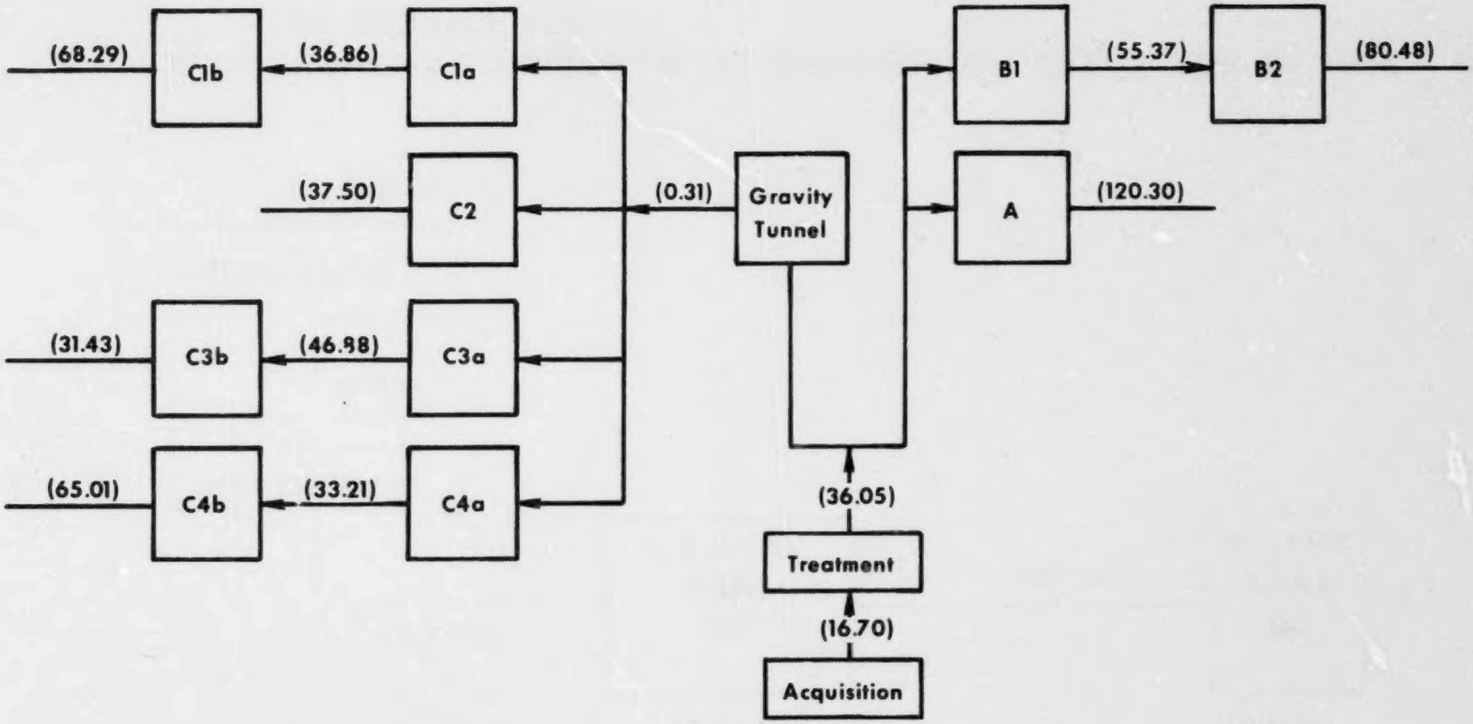
(68.29)
C1b
(36.86)
C1a
(37.50)
C2
(31.43)
C3b
(46.98)
C3a
(65.01)
C4b
(33.21)
C4a
(0.31)
Gravity Tunnel
B1
(55.37)
B2
(80.48)
A
(120.30)
(36.05)
Treatment
(16.70)
Acquisition

FIG. 21 SCHEMATIC DIAGRAM OF FACILITY COSTS IN CINCINNATI WATER WORKS SYSTEM. *

* (COSTS IN $/MIL GAL OF REVENUE PRODUCING WATER)

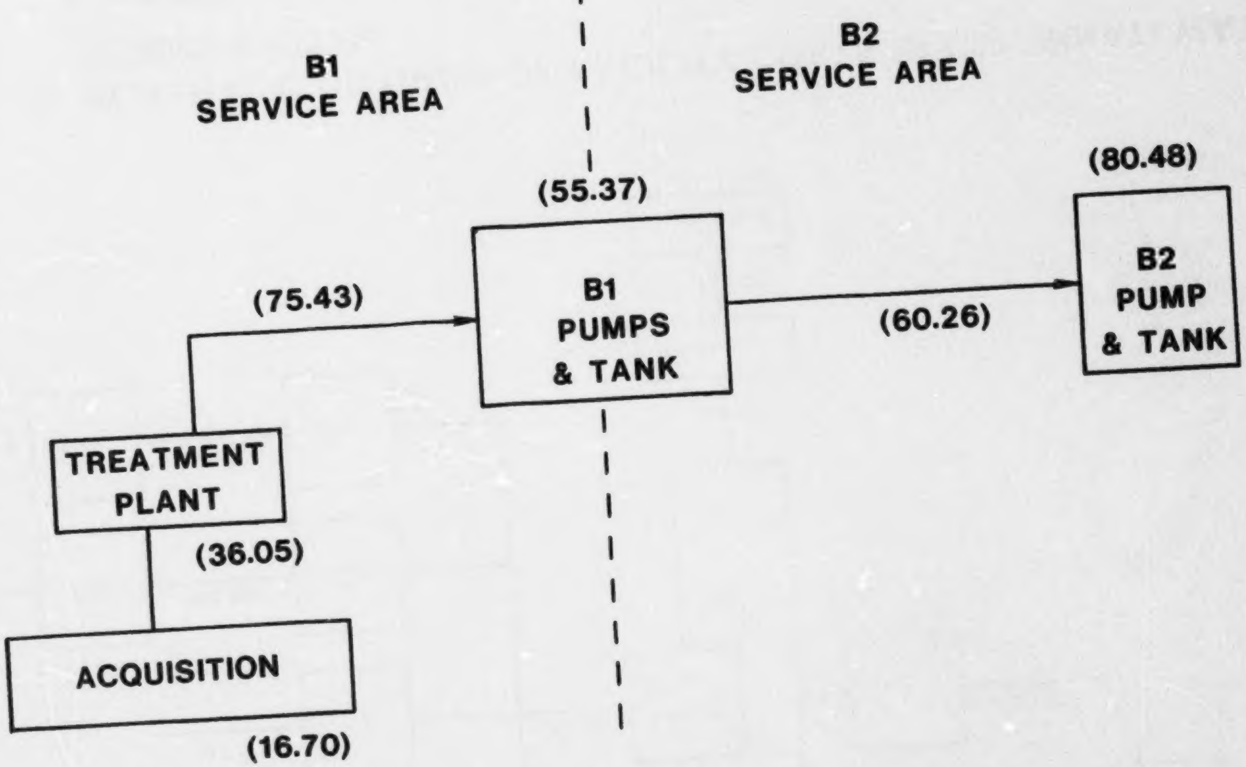
B1
SERVICE AREA
B2
SERVICE AREA
(55.37)
(80.48)
(75.43)
B1
PUMPS
& TANK
(60.26)
B2
PUMP
& TANK
TREATMENT
PLANT
(36.05)
ACQUISITION
(16.70)

FIG. 22 SCHEMATIC DIAGRAM OF INCREMENTAL COSTS FOR B1 AND B2 SERVICE AREAS *

* (COST IN $/MIL GAL OF REVENUE PRODUCING WATER)

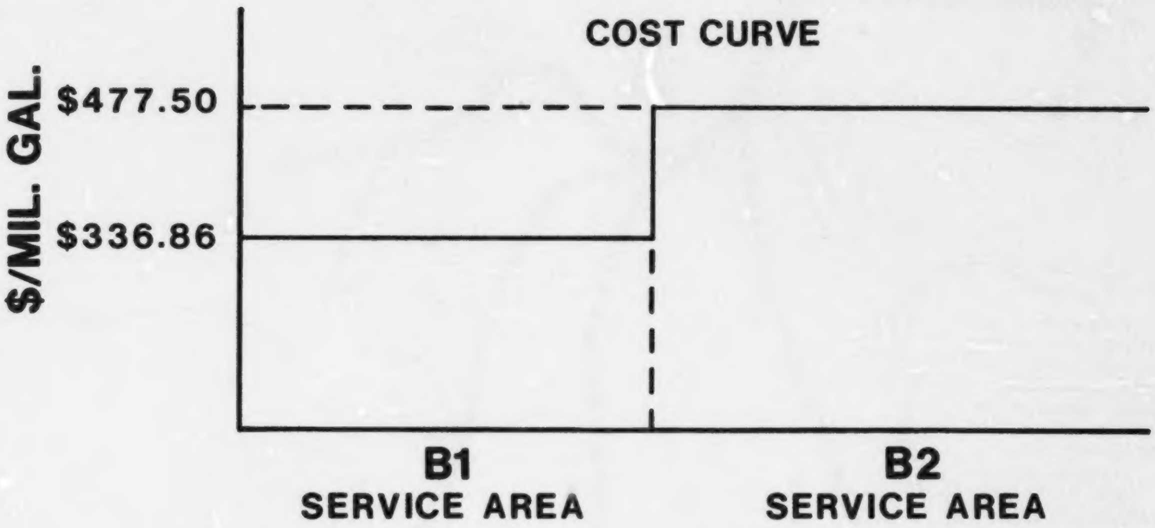

FIG. 23 Step function cost curve for B1 and B2 service areas.

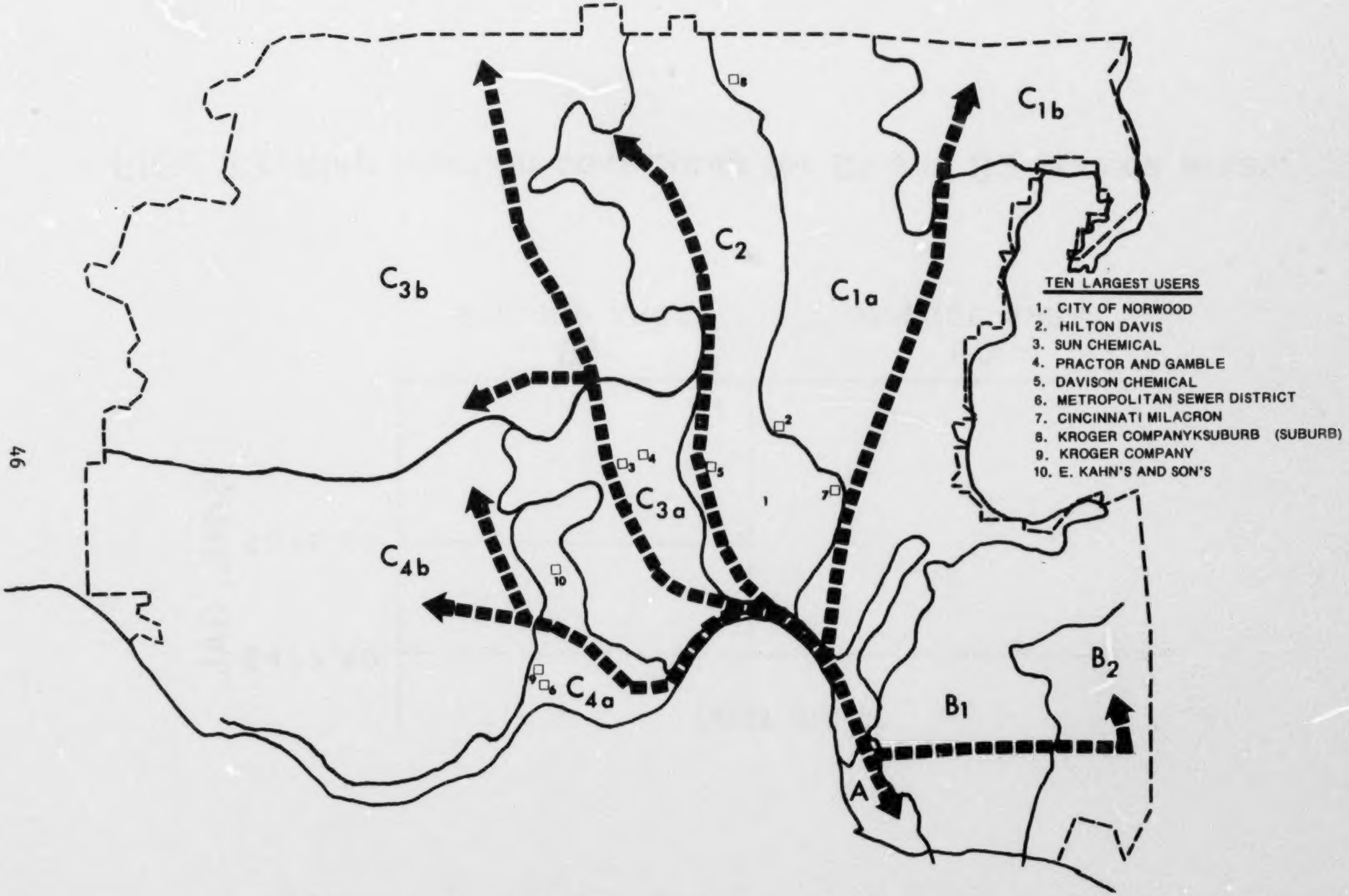
C1b
C2
C1a
C3b
C3a
C4b
C4a
B1
B2
A
TEN LARGEST USERS
1. CITY OF NORWOOD
2. HILTON DAVIS
3. SUN CHEMICAL
4. PRACTOR AND GAMBLE
5. DAVISON CHEMICAL
6. METROPOLITAN SEWER DISTRICT
7. CINCINNATI MILACRON
8. KROGER COMPANYKSUBURB (SUBURB)
9. KROGER COMPANY
10. E. KAHN'S AND SON'S
1
2
3
4
5
6
7
8
9
10

FIG. 24 MAJOR USERS IN CINCINNATI WATER WORKS SERVICE AREA

TABLE 9. ACTUAL CHARGE VERSUS REAL COST FOR TEN MAJOR USERS IN CINCINNATI WATER WORKS

($/mil gal)

User	Revenue*	Cost+	Adjusted cost+
Norwood	$ 294.12	$ 272.80	$ 243.52
Hilton Davis	168.83 175.67	262.99	233.71
Sun Chemical	169.87 175.44	275.54	246.26
Procter & Gamble	308.70 321.12	275.54	246.26
Davison Chemical	87.54 180.26	272.80	243.57
Metropolitan Sewer	175.19 185.44	264.56	235.28
Cincinnati Milacron	175.07 187.95	272.80	243.52
Kroger Company (Suburb)‡	313.54 328.26	262.99	233.71
Kroger Company	181.90 197.73	264.56	235.28
E. Kahn's Sons	181.67 195.17	264.56	235.28

* Wherever two values are presented, one represents the high and the other the low bill in $/mil gal for 1973-74.

+ These values were calculated on an average cost basis and as such do not reflect potential economies of scale that result from having large users in the system.

‡ Suburban users are charged at a higher rate to allow for expansion into Hamilton County.

such as water supply. The Dallas Water Utility provides water on a retail basis to all classes of customers within the city of Dallas, and provides wholesale water to 16 other communities within the county.

Organizationally, the Dallas Water Utility combines both water supply and wastewater treatment functions. It is composed of three sections: engineering and planning, operations, and business.

Raw water comes from five major reservoirs and is treated in three separate treatment plants in the northwest, central, and southeastern sections of the city. The treatment plants are generally located in the low-lying areas of the city, thus requiring that water be pumped up to residences and businesses at higher elevations.

The placement of the treatment plants represents an interesting example of decentralization to minimize the cost of delivering water to the consumer. Figure 25 shows the locations of plants and pumping facilities relative to the service area. The Elm Fork, Bachman, and East Side treatment plants ring the service area, thereby reducing the incremental cost of supplying water to the service area.

Figure 26 illustrates the substantial growth in consumer demand for water over the 10-year period of analysis.

Cost Analysis

Operating costs were categorized as follows: acquisition, treatment, transmission and distribution, power and pumping, and support services. Table 10 summarizes the historic costs in these areas for the study period. During these 10 years, the actual accounting system changed three times, making it difficult to track some of the specific cost items.

Table 10 shows that the total operating cost of water has increased from \$5.7 million to \$12.5 million (see also Figure 27). The cost of support services has increased at a faster rate, from \$1.4 million to \$4.7 million. On a unit basis, the total operating cost of water supply has increased from \$144.80/mil gal to \$198.76/mil gal, with the greatest increase occurring in support services -- from \$34.51/mil gal to \$74.57/mil gal in 1973-74 (Figure 28). Table 10 also shows each operating cost category as a percent of total operating cost, thus making it possible to identify where shifts have occurred in the proportion of money committed to a given task. Figure 29 gives a graphic representation of these shifts.

The unit operating cost in Dallas has not increased as fast as total cost over the 10-year period. Also, the cost/mil gal fluctuates based on the actual amount of water required in any given year. This fluctuation results from the ability of a given work force to produce a variable amount of water. Thus, if the demand is heavier during the year because of an unusual drought, water consumption will be higher without a proportional increase in cost. The reverse is also true. If the water usage is low because of unusual

□ ***Treatment Plants***

EF Elm Fork (458 ft.)
B Bachman (456 ft.)
ES East Side (480 ft.)

○ ***Pump Stations***

B Beltwood (622 ft.)
CW Camp Wisdom (693 ft.)
CC Cosa Crest (620 ft.)
G Greenville (609 ft.)
JM Jim Miller (521 ft.)
LJ Lake June (504 ft.)
SC Southcliff (586 ft.)
S Sunset (607 ft.)
WC Walcrest (627 ft.)
CV Casa View (562 ft.)
WH Walnut Hill

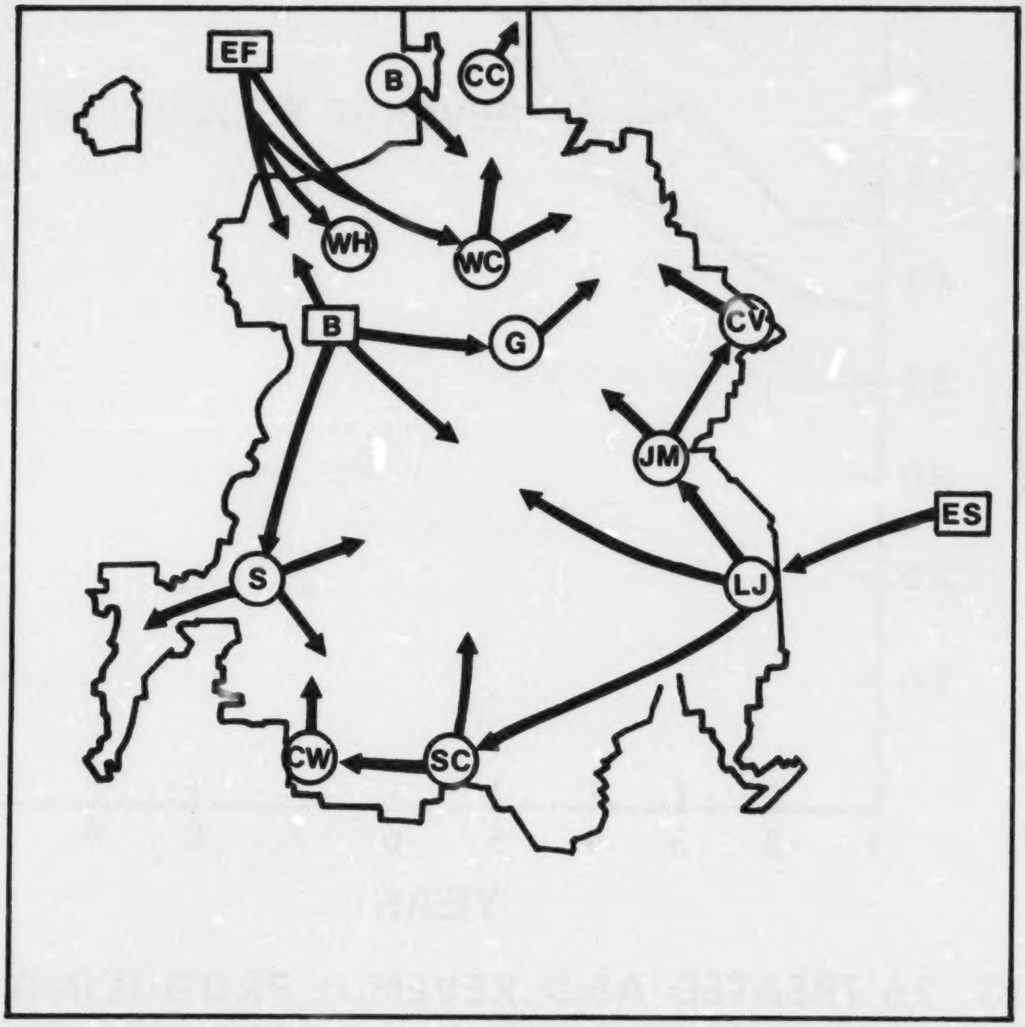

FIG. 25 TREATMENT PLANTS AND PUMP STATIONS IN DALLAS UTILITIES SERVICE AREA

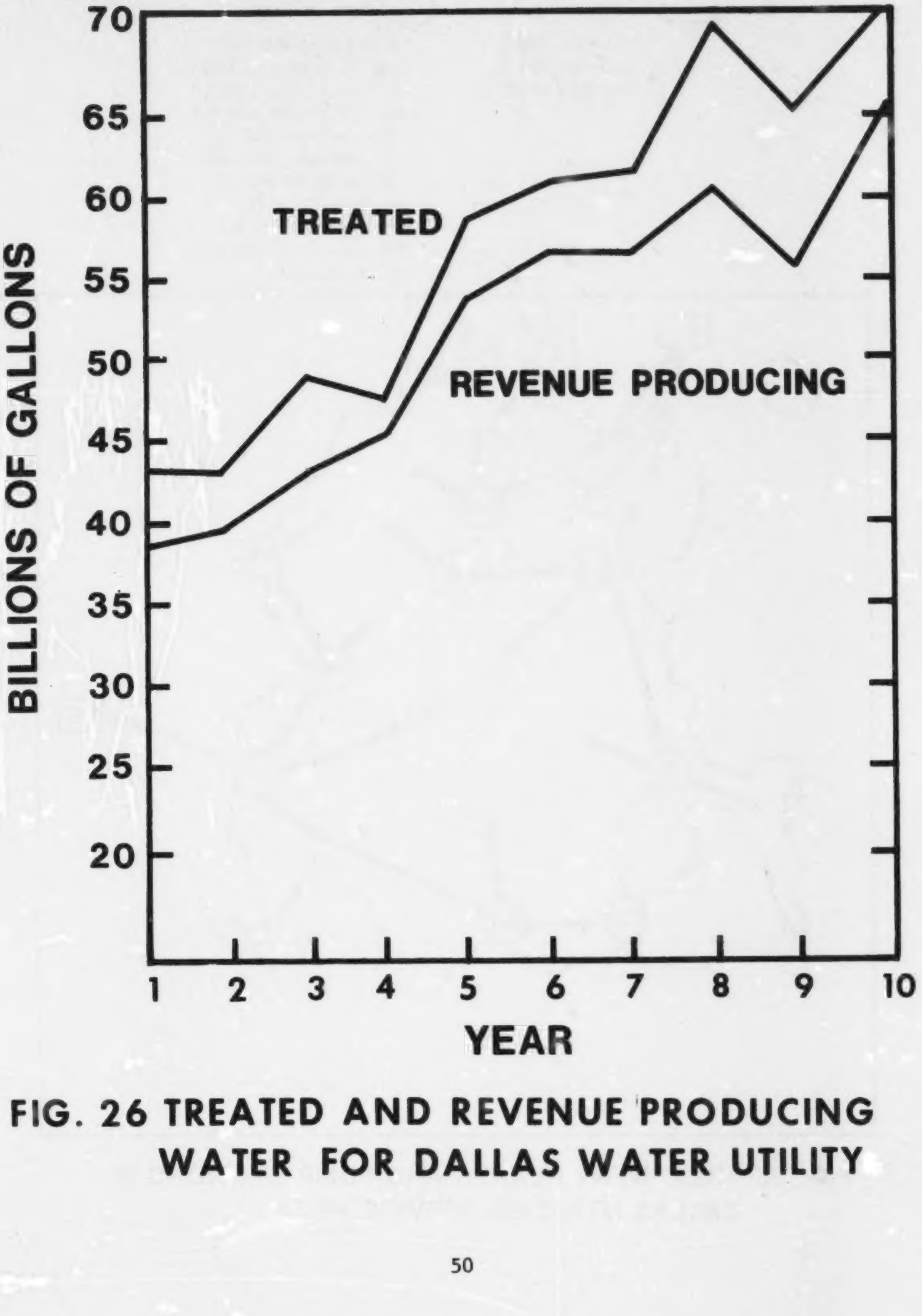

FIG. 26 TREATED AND REVENUE PRODUCING WATER FOR DALLAS WATER UTILITY

TABLE 10. SUMMARY OF OPERATING AND CAPITAL EXPENDITURES FOR 1965-74 FOR DALLAS WATER UTILITY

Item	Year									
	1	2	3	4	5	6	7	8	9	10
OPERATING COSTS:										
Support services:										
$, in millions	1.355	1.450	1.664	1.873	2.285	2.670	3.492	3.764	4.403	4.700
% of total	23.83	24.13	25.61	27.19	29.16	30.86	35.28	34.67	35.53	37.54
$/mil gal	34.51	36.82	38.57	41.27	42.76	47.29	61.75	62.02	78.63	74.57
Acquisition:										
$, in millions	.524	.538	.597	.515	.495	.501	.578	.533	.756	.688
% of total	9.22	8.95	9.20	7.48	6.32	5.79	5.83	4.91	6.10	5.49
$/mil gal	13.35	13.65	13.85	11.35	9.26	8.87	10.21	8.79	13.50	10.92
Treatment:										
$, in millions	1.377	1.449	1.448	1.510	1.759	1.902	2.206	2.307	2.573	2.788
% of total	24.23	24.09	22.29	21.92	22.44	21.97	22.27	21.24	20.76	22.25
$/mil gal	35.07	36.76	33.57	33.27	32.90	33.67	39.01	38.01	45.95	44.24
Power and pumping:										
$, in millions	.999	1.003	1.094	1.143	1.336	1.404	1.521	1.781	1.908	1.806
% of total	17.57	16.69	16.84	16.59	17.04	16.22	15.36	16.40	15.40	14.41
$/mil gal	25.44	25.46	25.36	25.19	24.98	24.86	26.89	29.34	34.07	28.66
Transmission and distribution:										
$, in millions	1.431	1.572	1.692	1.847	1.963	2.179	2.104	2.473	2.751	2.545
% of total	25.16	26.15	26.05	26.81	25.04	25.17	21.24	22.77	22.20	20.32
$/mil gal	36.43	39.90	39.24	40.70	36.71	38.57	37.20	40.73	49.13	40.37
Total operating costs:										
$, in millions	5.686	6.012	6.496	6.887	7.838	8.656	9.901	10.859	12.390	12.528
$/mil gal	144.80	152.59	150.29	151.78	146.61	153.26	175.06	178.89	221.28	198.76

TABLE 10 (Continued). SUMMARY OF OPERATING AND CAPITAL EXPENDITURES FOR 1965-74 FOR DALLAS WATER UTILITY

Item	Year									
	1	2	3	4	5	6	7	8	9	10
CAPITAL COSTS:										
Depreciation ($, in millions)	2.979	3.176	3.339	3.494	3.688	3.815	3.986	4.407	4.752	5.135
Interest ($, in millions)	1.918	1.951	2.088	2.246	2.196	2.804	2.193	2.509	3.425	3.638
Total capital costs ($, in millions)	4.397	5.127	5.427	5.740	5.884	5.899	6.179	6.916	8.176	8.773
TOTAL OPERATING AND CAPITAL COSTS:										
$, in millions	10.583	11.140	11.924	12.627	13.722	14.555	16.079	17.775	20.567	21.301
$/mil gal	269.46	282.70	276.42	278.30	256.72	257.72	284.31	292.83	367.29	337.94

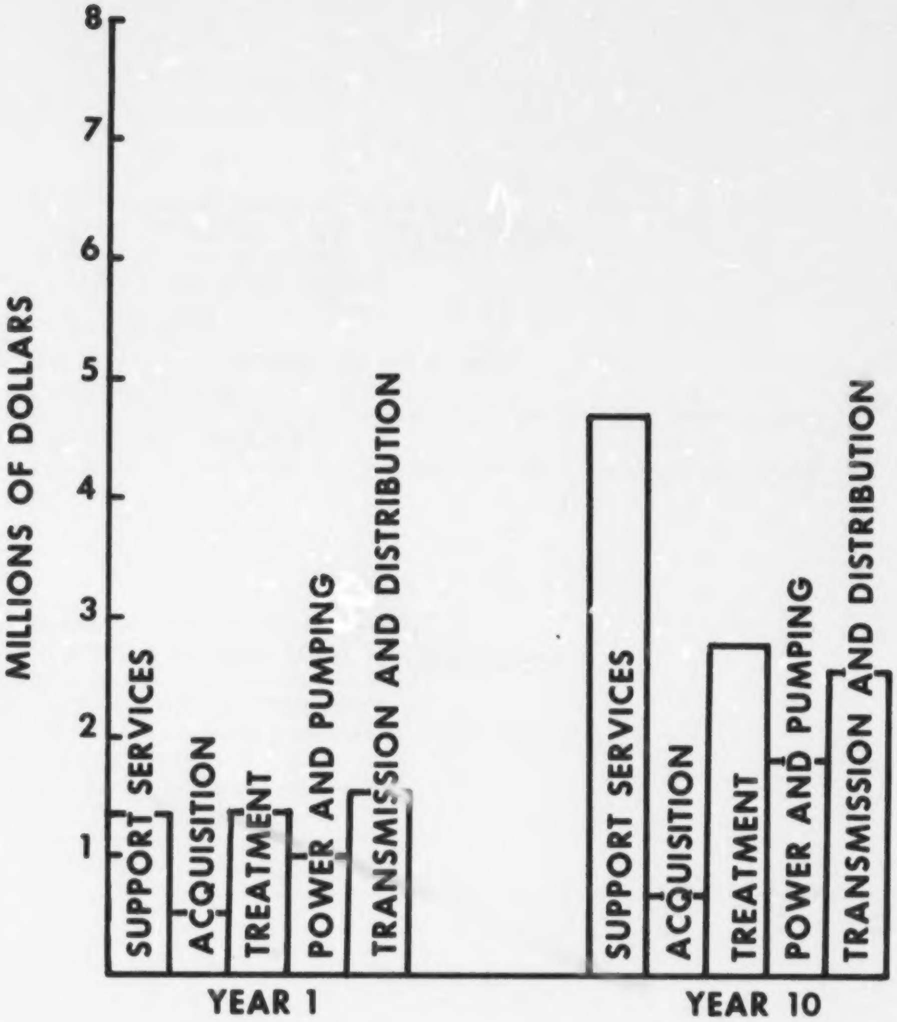

FIG. 27 OPERATING COSTS FOR DALLAS WATER UTILITY

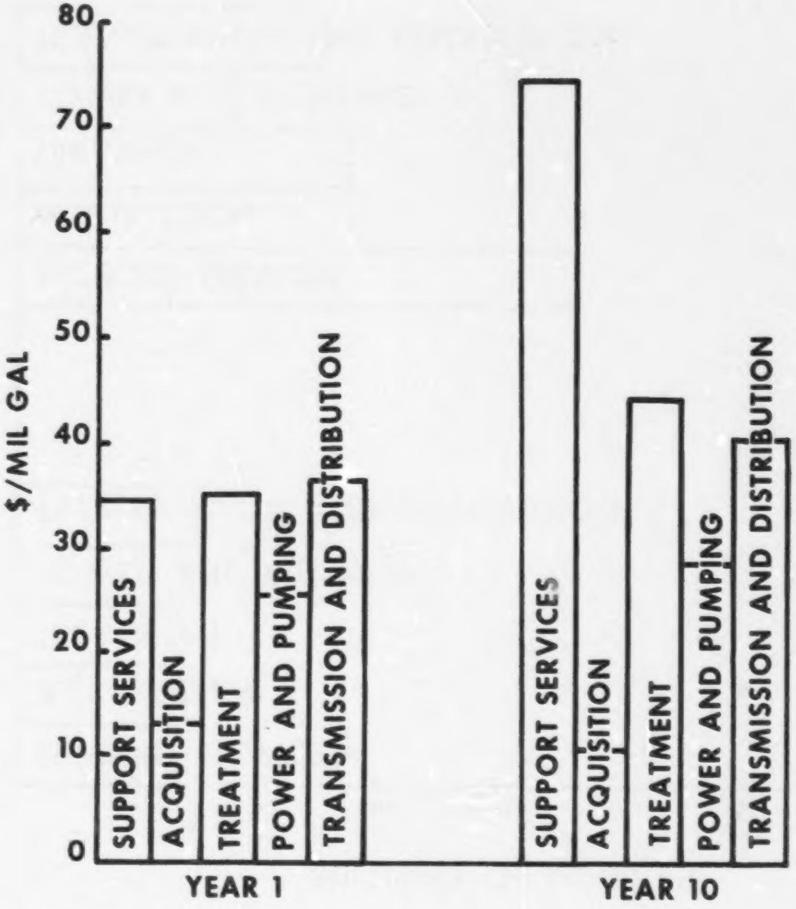

FIG. 28 OPERATING COSTS IN $/MIL GAL FOR DALLAS WATER UTILITY

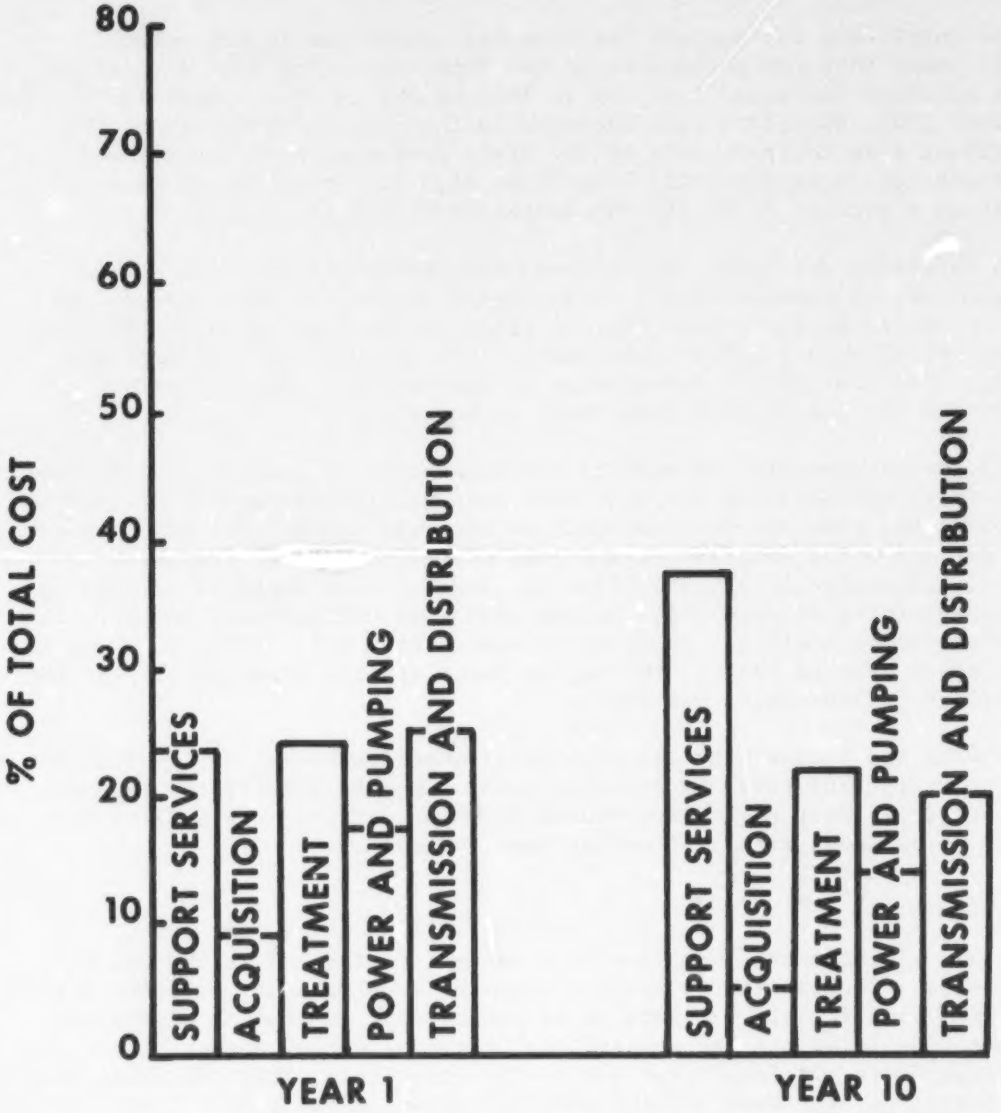

FIG. 29 OPERATING COST AS PERCENT OF TOTAL COST FOR DALLAS WATER UTILITY

conditions, such as excessive rain, the water consumption will be reduced without a corresponding reduction in operating cost. This principle was illustrated in the latest study year when the water consumption significantly decreased and caused an increase in unit operating costs.

The total cost for support services has significantly increased. Table 10 shows that the proportion of the total operating cost devoted to support services increased from 24% in 1964 to 38% in 1973. Cost in each year must total 100%, therefore this increase in the support services category must reflect a decrease in some of the other operating cost categories. For acquisition, which is primarily associated with the operation of reservoirs, the cost as a percent of total cost decreased from 9.2% to 5.4%.

To determine the total cost of producing water, it is necessary to calculate capital expenditures. As discussed earlier in this report, the method chosen is to depreciate the net plant in service, based on original purchase price, on a straight line basis, over the estimated life of the facility. The cost of borrowing money is considered to be the actual interest paid by the utility when money is borrowed.

For the purpose of this report, the total cost of producing water is considered to be operating expenses plus depreciation of capital equipment and facilities, plus the interest paid on borrowed money. The total cost in Dallas for producing water increased from approximately $10.5 million in year 1 to approximately $21.3 million in year 10 -- an increase of 102% in total expenditures (Figure 30). During that same time period, however, the cost of producing a mil gal of water increased only 25%. Table 10 shows that in the latest year of record, the Dallas Water Utility expended $337.94 for each million gallons sold that year.

As with the Kansas City and Cincinnati water supplies, the capital costs, operating costs, and total expenditures over time are illustrated (Figures 31 through 33). Unit costs have decreased on a corrected basis using the Consumer Price Index with 1965 as the base year.

System Evaluation

Figure 25 shows the locations of treatment facilities in the Dallas service area. Because the facilities ring the service area, relating cost to distance is difficult. Figure 34 is a schematic diagram of the Dallas treatment facilities and the capital and operating expenses they incur. Costs assigned to the facilities and to the other cost categories that make up the total cost for each service zone are shown in Table 11. Figure 35 illustrates the cost increases that are incurred from the East Fork treatment plant to the Cosa Crest service area. This is simply another illustration of the way in which costs can be seen to vary with distance from the treatment plant.

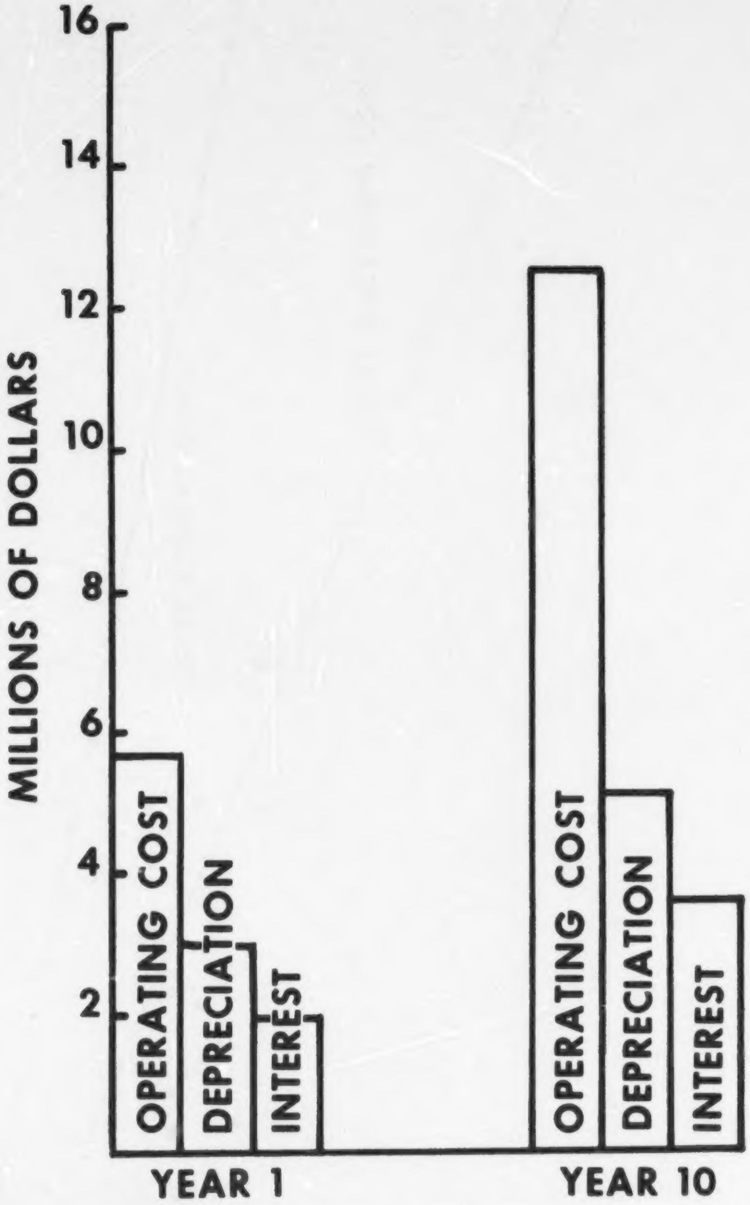

FIG. 30 OPERATING AND CAPITAL COSTS FOR DALLAS WATER UTILITY

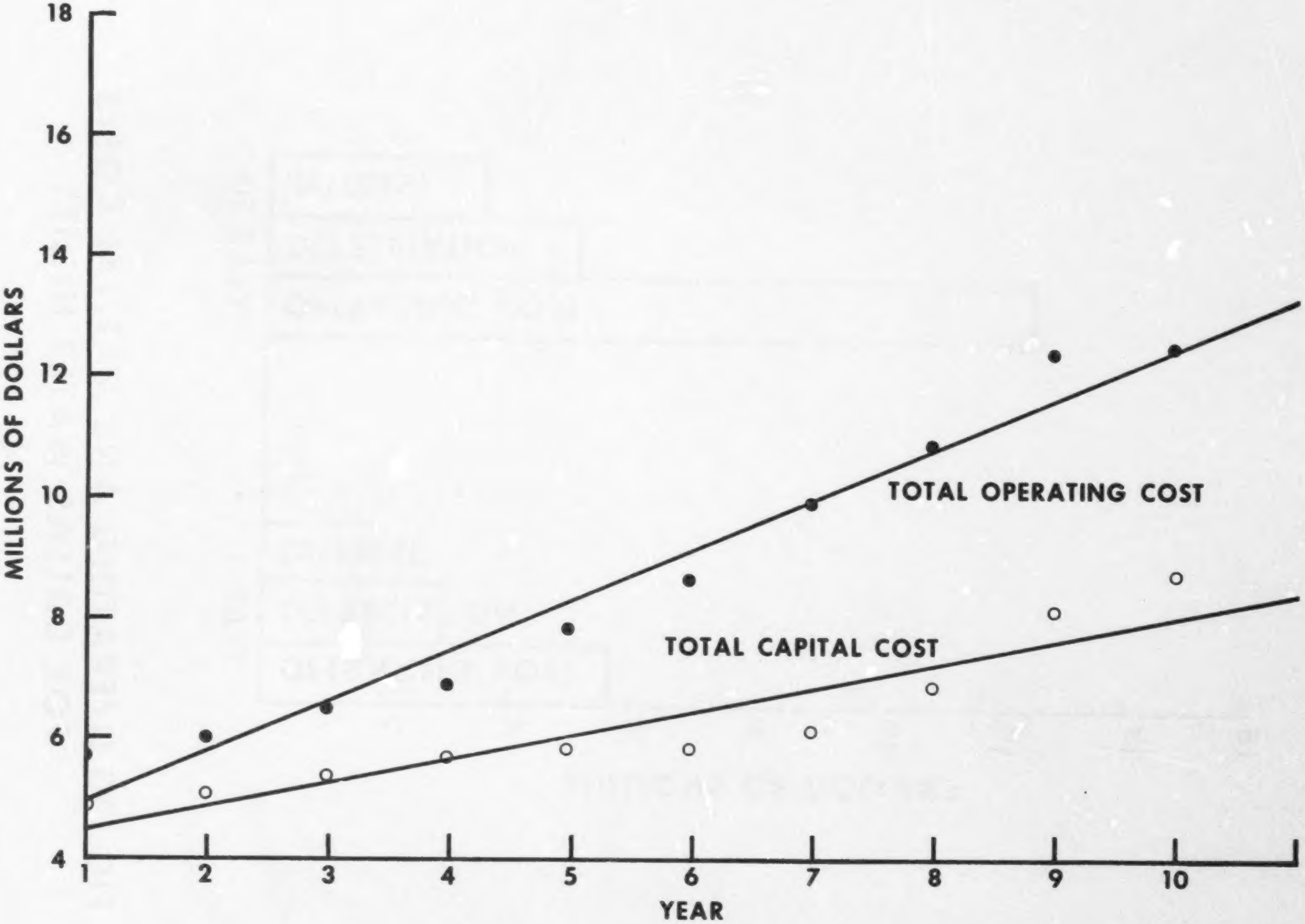

FIG. 31 OPERATING AND CAPITAL EXPENDITURES FOR DALLAS WATER UTILITY

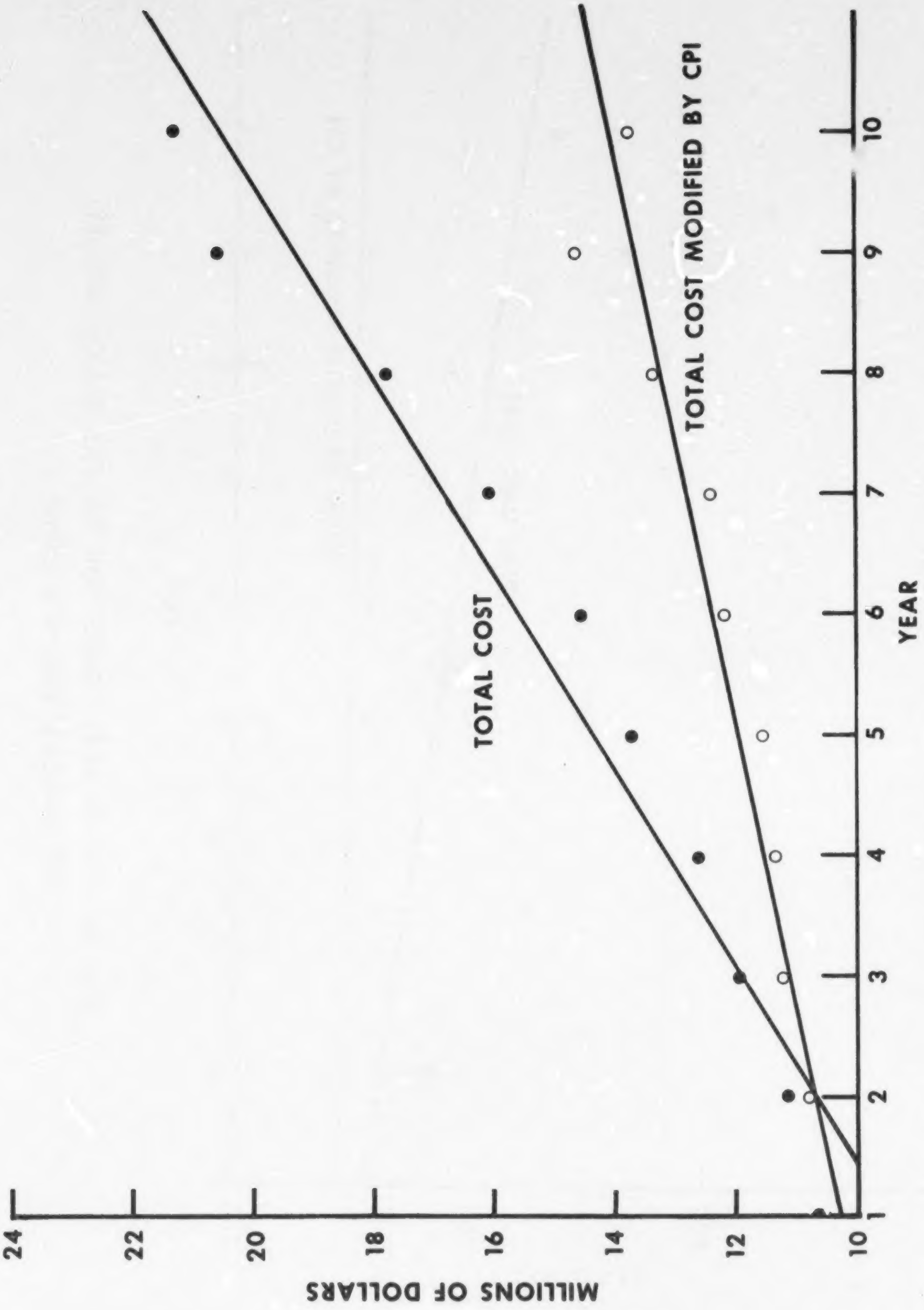

FIG. 32 TOTAL EXPENDITURES FOR DALLAS WATER UTILITY: HISTORICAL AND MODIFIED

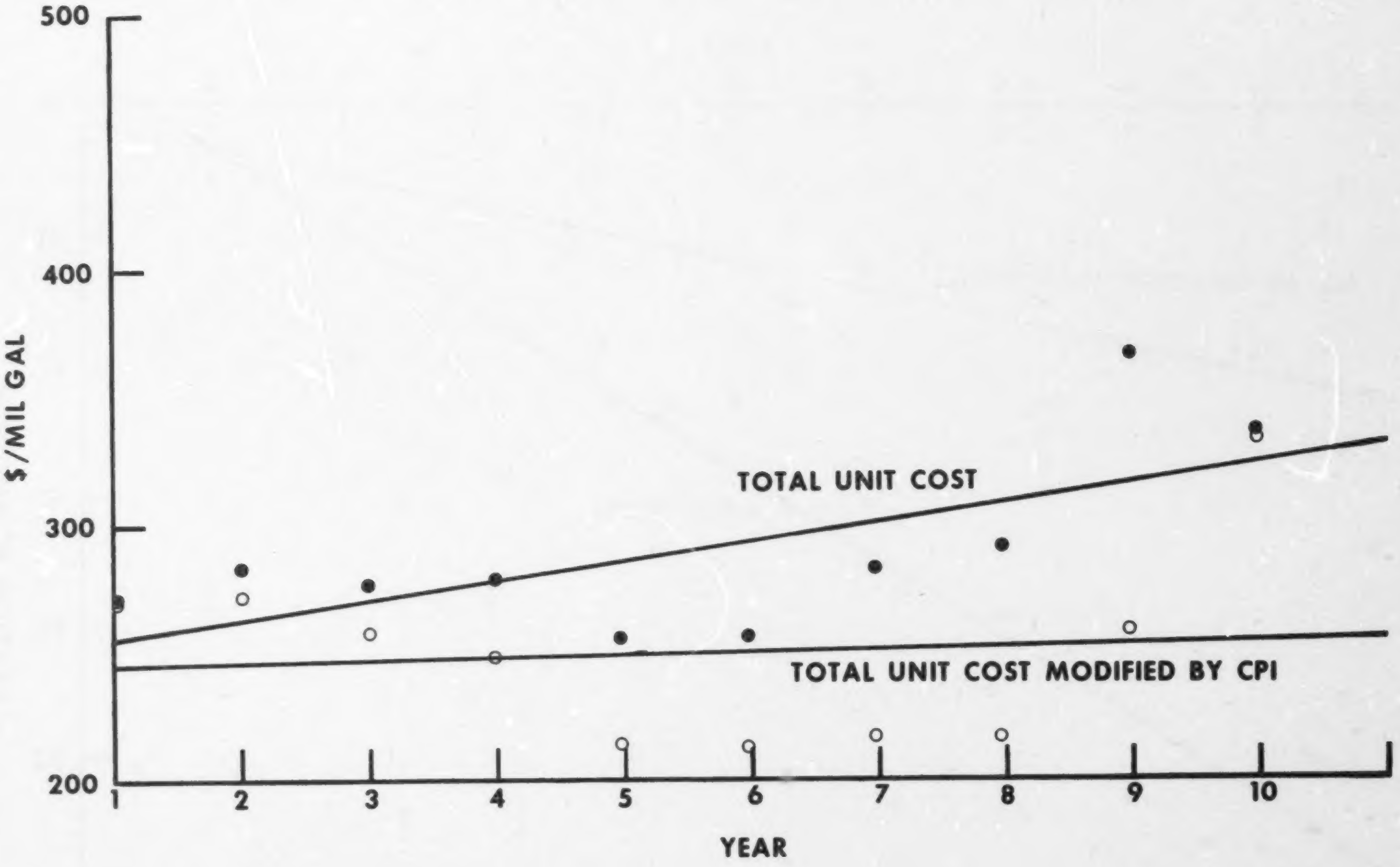

FIG. 33 TOTAL UNIT COSTS FOR DALLAS WATER UTILITY: HISTORICAL AND MODIFIED

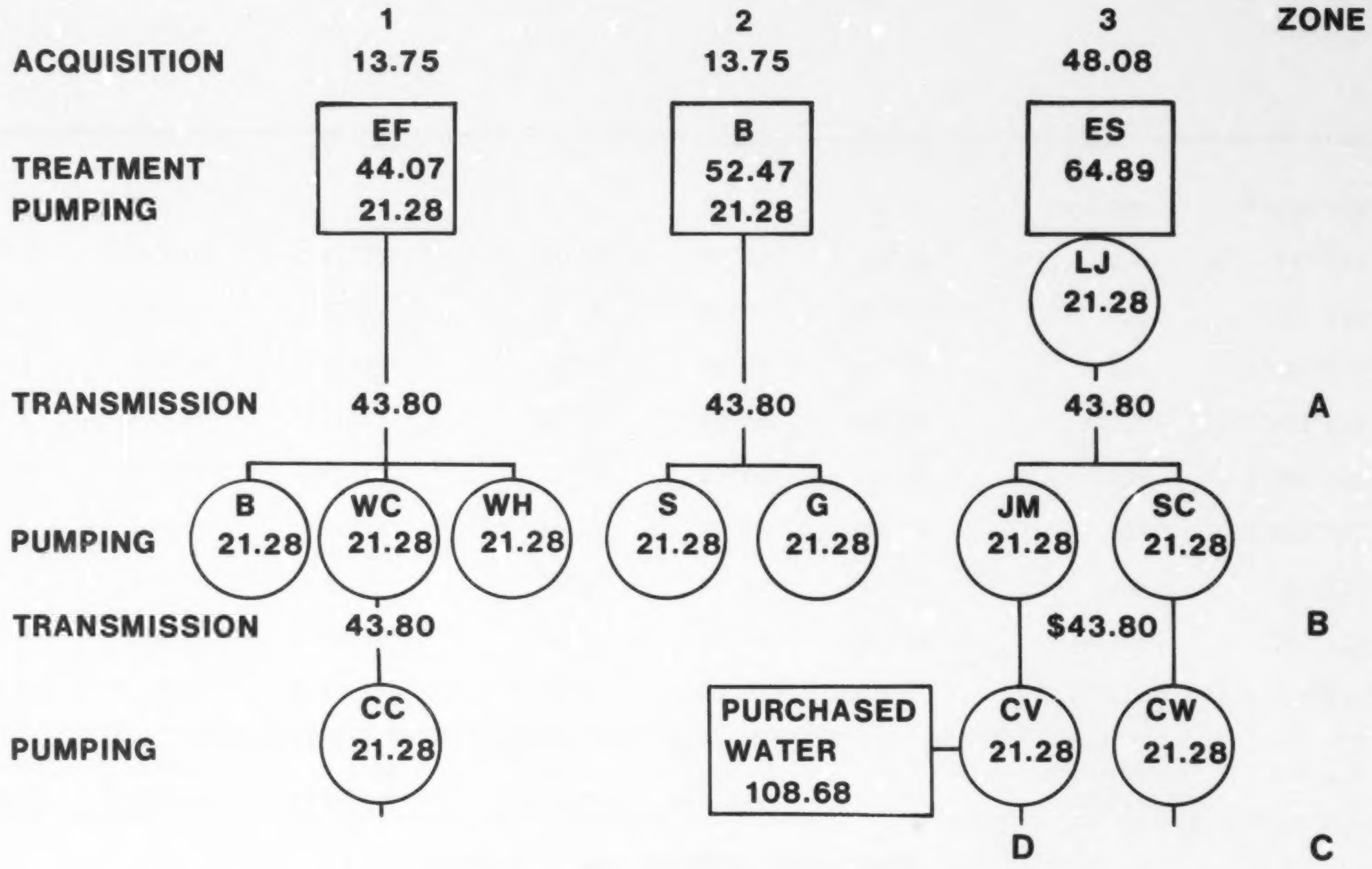
1
2
3
ZONE
ACQUISITION
13.75
13.75
48.08
TREATMENT
PUMPING
EF
44.07
21.28
B
52.47
21.28
ES
64.89
LJ
21.28
TRANSMISSION
43.80
43.80
43.80
A
PUMPING
B
21.28
WC
21.28
WH
21.28
S
21.28
G
21.28
JM
21.28
SC
21.28
TRANSMISSION
43.80
$43.80
B
PUMPING
CC
21.28
PURCHASED
WATER
108.68
CV
21.28
CW
21.28
D
C

FIG. 34 ALLOCATION OF CAPITAL AND OPERATING EXPENSES TO WATER SYSTEM COMPONENTS FOR DALLAS WATER UTILITY (COSTS IN $/MIL GAL OF REVENUE PRODUCING WATER)

TABLE 11. COST ELEMENTS FOR SERVICE ZONES

Cost zone	Incremental cost ($/mil gal)	Distribution cost ($/mil gal)	Interest cost ($/mil gal)	Overhead cost ($/mil gal)	Total cost ($/mil gal)	Metered consumption (mil gal)	Revenue
1 A	$ 70.90	$ 67.33	$ 57.72	$ 83.46	$279.41	16,766	$ 4,684,588.06
B	132.25	67.33	57.72	83.46	340.76	16,323	5,562,225.48
C	193.60	67.33	57.72	83.46	402.11	334	89.670,53
2 A	104.66	67.33	57.72	83.46	313.16	872	2,465,274.24
B	166.01	67.33	57.72	83.46	374.52	854	2,566,960.08
3 A	153.04	67.33	57.72	83.46	361.55	4,212	1,522,848.60
B	214.39	67.33	57.72	83.46	422.90	5,936	2,933,234.40
C	275.74	67.33	57.72	83.46	484.25	87	623,299.75
3 D	129.96	67.33	57.72	83.46	333.88	557	853,731.16
					337.96	63,030	21,301,762.30

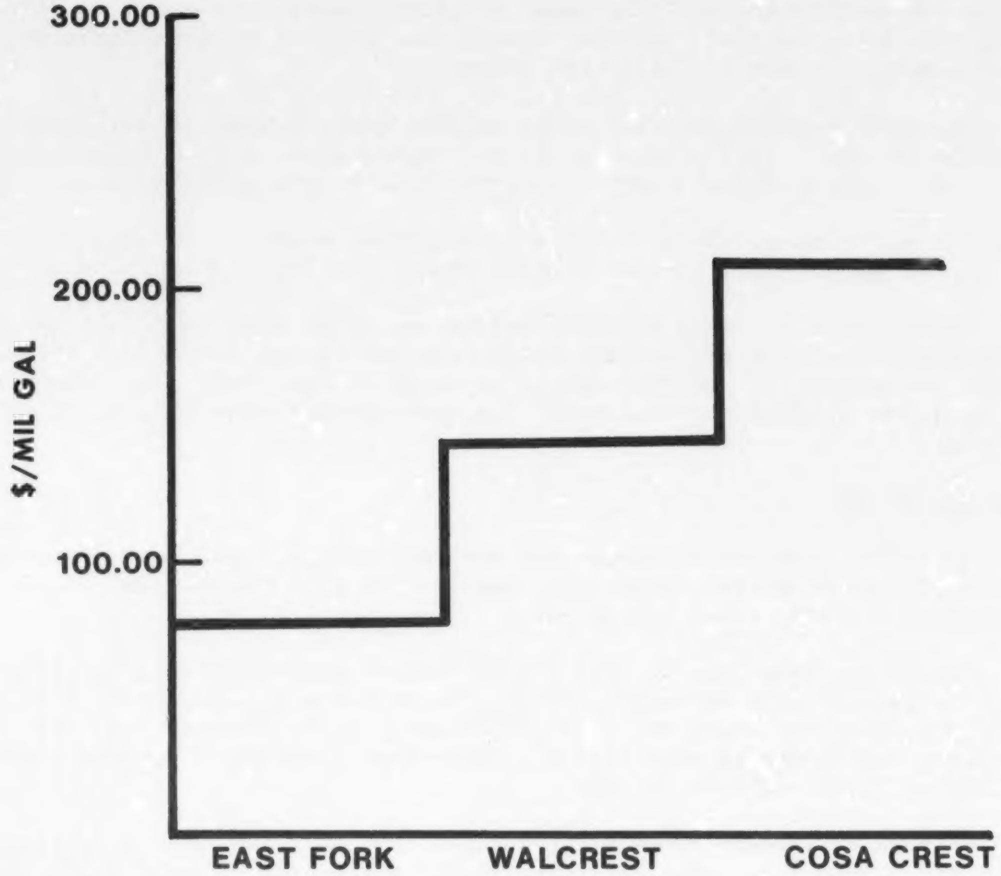

FIG. 35 COST OF SERVICE OVER PATHWAY 1

ELIZABETHTOWN WATER COMPANY

The Elizabethtown Water Company provides water to five counties in New Jersey -- Union, Summerset, Mercer, Middlesex, and Hunterden. The service population, which was 507,836 in the last year of analysis, has remained relatively stable, but water consumption has increased by 30% over the last three years.

This utility is investor-owned and as such has some different characteristics compared to the publicly-owned utilities mentioned earlier. One difference is a liability for real estate tax incurred by the Elizabethtown Water Company but not by public utilities.

Organizationally, the utility is controlled by a board of directors and consists of four organizational entities: operations, controller, business, and legal. The president reports directly to the chairperson of the board.

Raw water comes from both surface and ground sources. Approximately 77% of the source water is from surface water, and 23% is from the ground.

Figure 36 illustrates consumer demand for water over the 10-year period. Treated water is that pumped from wells, treated in one of the four treatment plants, or purchased. Revenue-producing water is that water that is metered and paid for by wholesale and retail customers of the Elizabethtown Water Company.

Cost Evaluation

Operating costs were categorized into acquisition, treatment, transmission and distribution, power and pumping, and support services. Table 12 summarizes historic costs for 10 years.

Operating costs were divided by millions of gallons of revenue-producing water to provide unit operating costs. The patterns of expenditure are similar to those of other utilities discussed. Table 12 shows that the utility's tax burden is significant. Taxes have increased from $2.646 million in 1965 to $3.935 million in 1974.

Figures 37 through 40 show the changes that have occurred in operating costs with respect to total cost, unit cost, percentage of total cost, and changes in O&M and capital cost. Total operating and capital costs over time, corrected by the CPI assuming 1965 as the base year are shown in Figures 41 through 43.

System Evaluation

The water distribution and treatment system for the Elizabethtown Water Company is complex because of the different acquisition points for water supply. Volume II contains a detailed evaluation of the system.

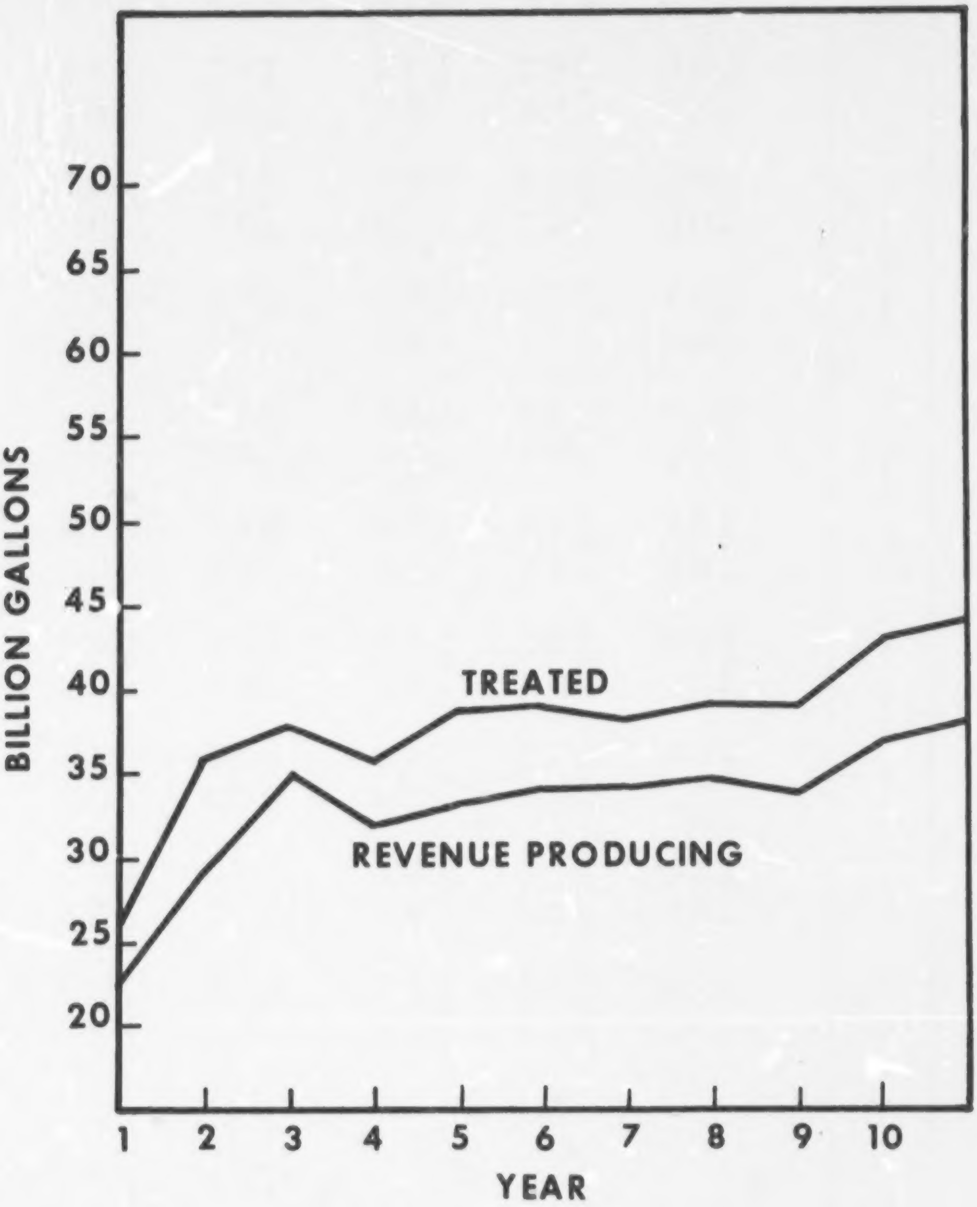

FIG.36 TREATED AND REVENUE PRODUCING WATER FOR ELIZABETHTOWN WATER COMPANY

TABLE 12. SUMMARY OF OPERATING AND CAPITAL EXPENDITURES FOR ELIZABETHTOWN WATER UTILITY

Item	Year									
	1	2	3	4	5	6	7	8	9	10
OPERATING COSTS:										
Support Services:										
$, in millions	1.192	1.305	1.392	1.449	1.766	2.108	2.277	2.351	2.677	3.028
% of total	32.15	30.07	30.74	30.08	32.24	35.57	34.39	33.59	34.18	31.38
$/mil gal	40.61	37.77	43.89	45.11	52.17	61.26	65.38	68.57	73.19	79.18
Acquisition:										
$, in millions	0.485	0.748	0.979	1.048	1.093	1.175	1.226	1.492	1.478	1.502
% of total	13.08	17.23	21.63	21.05	19.94	19.83	18.52	21.32	18.88	15.56
$/mil gal	16.52	21.64	30.88	31.55	32.27	34.15	35.21	43.52	40.42	39.28
Power and Pumping:										
$, in millions	0.964	1.079	1.043	1.104	1.161	1.132	1.408	1.412	1.818	2.710
% of total	26.00	24.86	23.02	22.16	21.20	19.09	21.28	20.18	23.21	28.09
$/mil gal	32.85	31.23	32.87	33.23	34.30	32.89	40.44	41.19	49.73	70.89
Transmission and Distribution:										
$, in millions	0.619	0.644	0.703	0.813	0.879	0.918	1.017	1.020	1.069	1.294
% of total	16.70	14.83	15.51	16.31	16.04	15.49	15.37	14.56	13.65	13.41
$/mil gal	21.09	18.63	22.15	24.46	25.96	26.68	29.21	29.73	29.23	33.84
Treatment:										
$, in millions	0.448	0.565	0.412	0.519	0.579	0.593	0.691	0.725	0.790	1.116
% of total	12.07	13.01	09.10	10.40	10.58	10.02	10.44	10.35	10.08	11.56
$/mil gal	15.25	16.34	13.00	15.60	17.11	17.25	19.85	21.14	21.59	29.18
Total Operating Costs:										
$, in millions	3.707	4.341	4.529	4.983	5.479	5.927	6.619	7.001	7.832	9.649
$/mil gal	126.32	125.61	142.79	149.95	161.81	172.23	190.09	204.15	214.16	252.37

TABLE 12 (Continued). SUMMARY OF OPERATING AND CAPITAL EXPENDITURES FOR ELIZABETHTOWN WATER UTILITY

Item	Year									
	1	2	3	4	5	6	7	8	9	10
CAPITAL COSTS:										
Depreciation:										
($, in millions)	0.915	1.004	1.079	1.145	1.200	1.297	1.352	1.418	1.521	1.693
Interest:										
($, in millions)	1.039	1.345	1.577	1.872	2.508	2.927	2.819	2.908	3.373	4.327
Total capital cost:										
($, in millions)	1.954	2.349	2.656	3.017	3.708	4.224	4.171	4.326	4.894	6.020
Total operating and capital cost:										
$, in millions	5.661	6.690	7.185	8.000	9.187	10.187	10.790	11.327	12.726	15.669
$/mil gal	192.89	193.55	226.58	240.70	271.31	296.05	309.86	330.32	347.97	409.81
Taxes ($, in millions)	2.646	2.658	2.324	2.559	3.561	3.392	3.210	3.030	4.617	3.935
Total Cost:										
$, in millions	8.307	9.348	9.509	10.559	12.748	13.543	14.000	14.357	17.343	19.604
$/mil gal	283.04	270.45	299.86	317.70	376.47	393.58	402.04	418.68	474.22	512.72

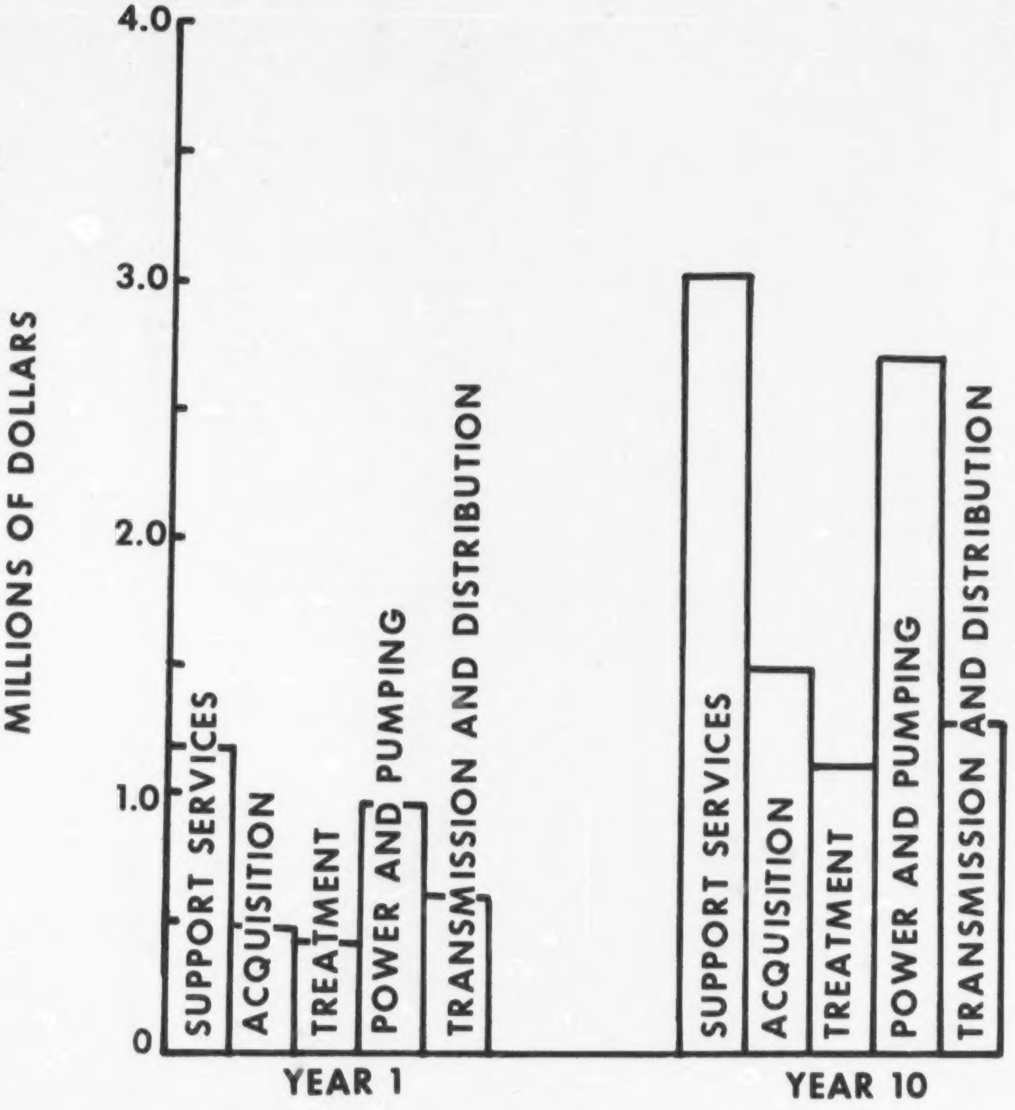

FIG. 37 OPERATING COSTS FOR ELIZABETH-TOWN WATER UTILITY

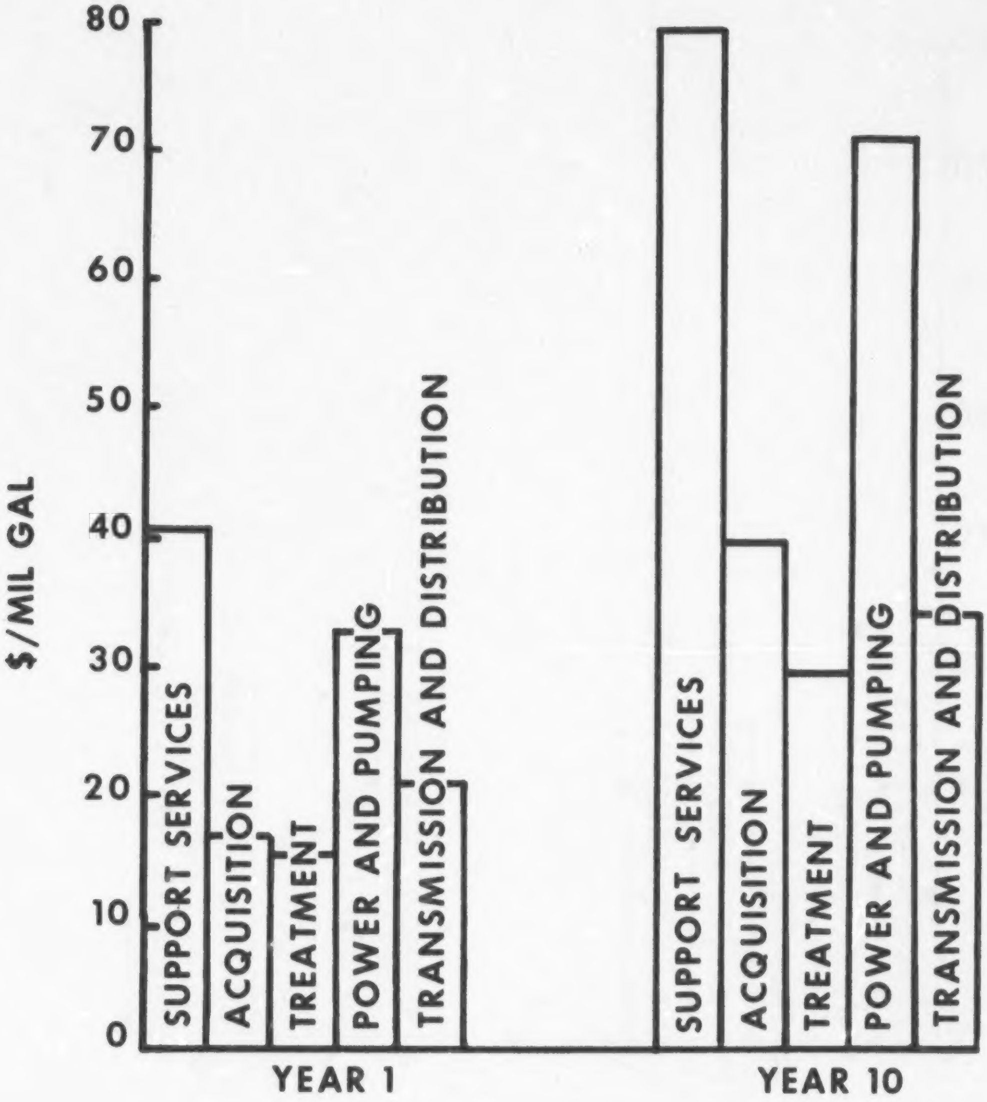

FIG. 38 OPERATING COST IN $/MIL GAL FOR ELIZABETHTOWN WATER UTILITY

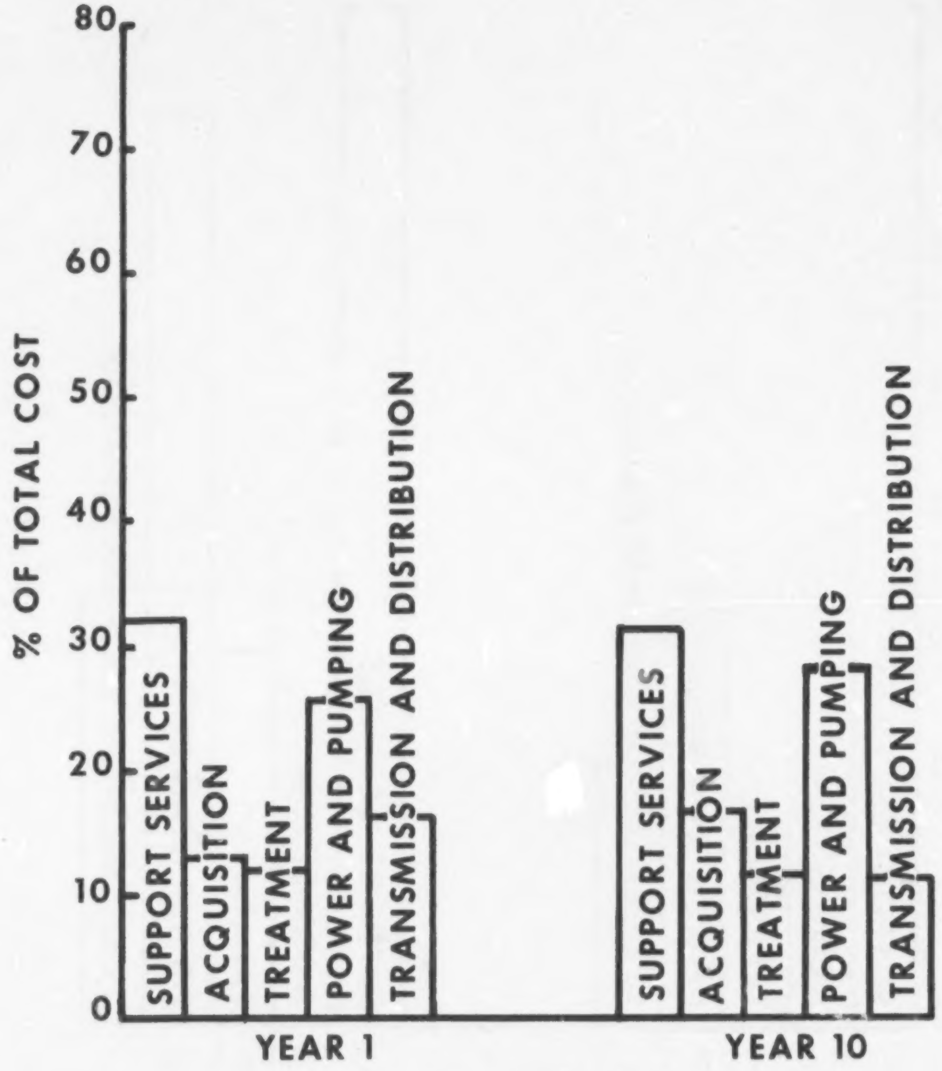

FIGURE 39

FIG. 39 OPERATING COST AS PERCENT OF TOTAL COST FOR ELIZABETHTOWN WATER UTILITY

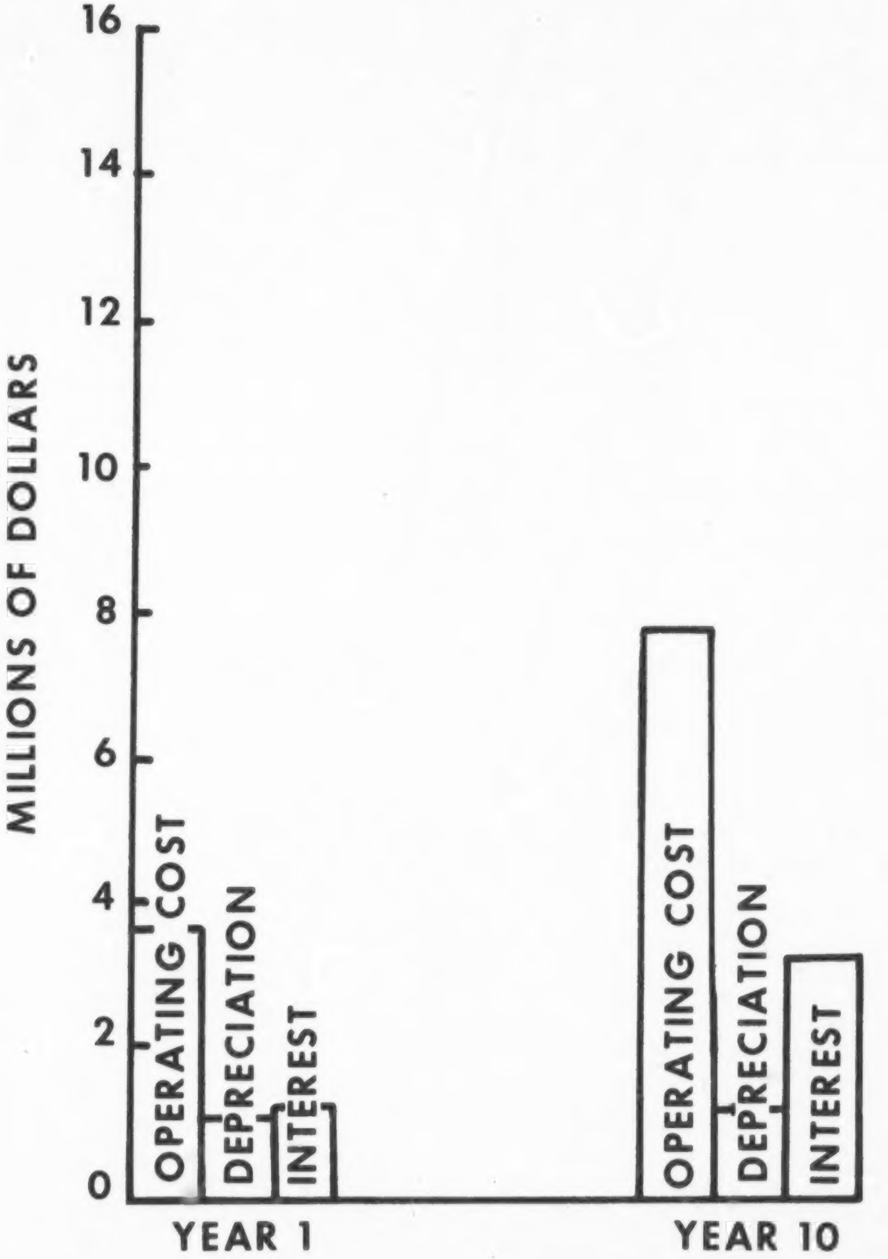

FIG. 40 OPERATING AND CAPITAL COSTS FOR ELIZABETHTOWN WATER UTILITY

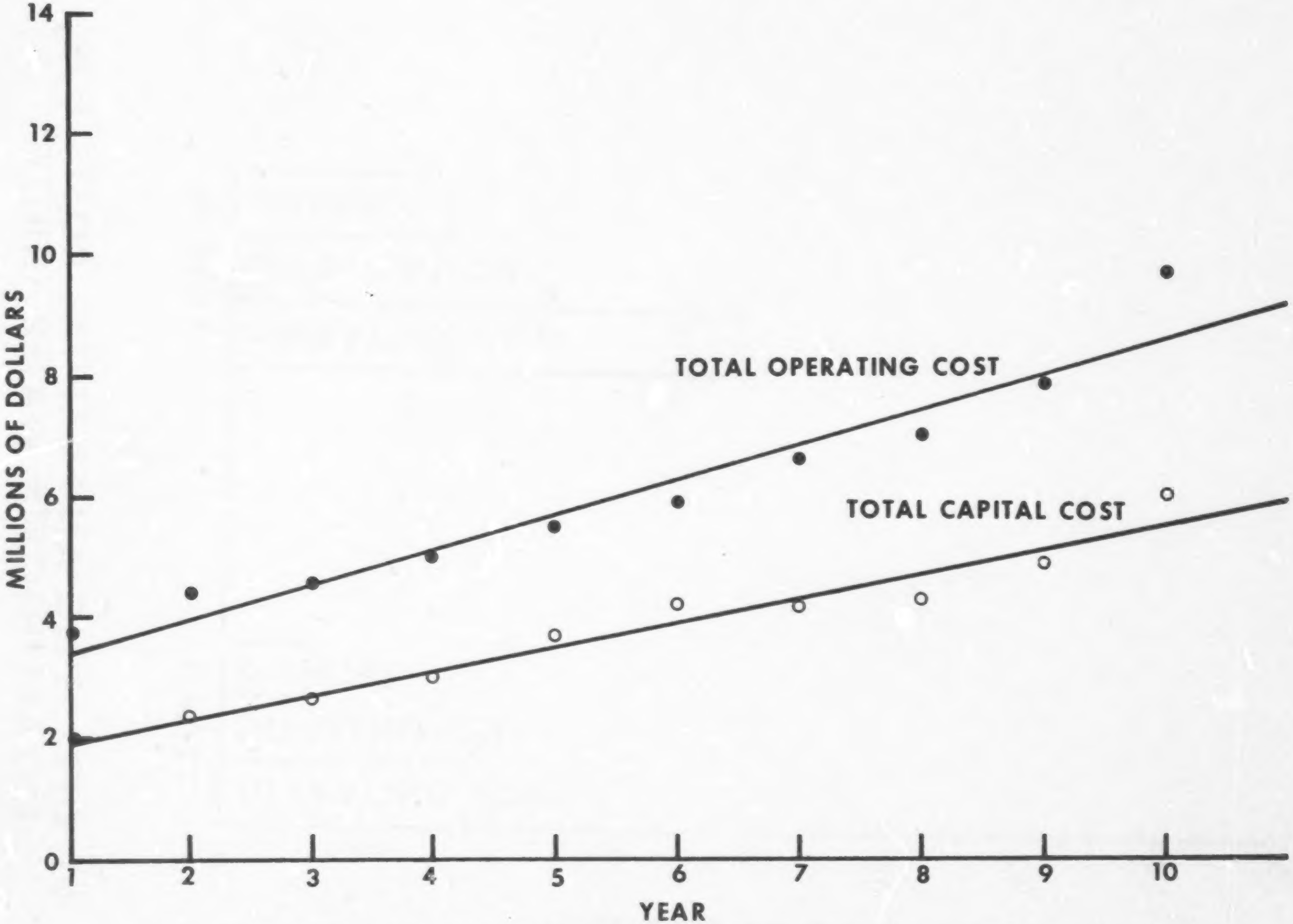

FIG. 41 OPERATING AND CAPITAL EXPENDITURES FOR ELIZABETHTOWN WATER COMPANY

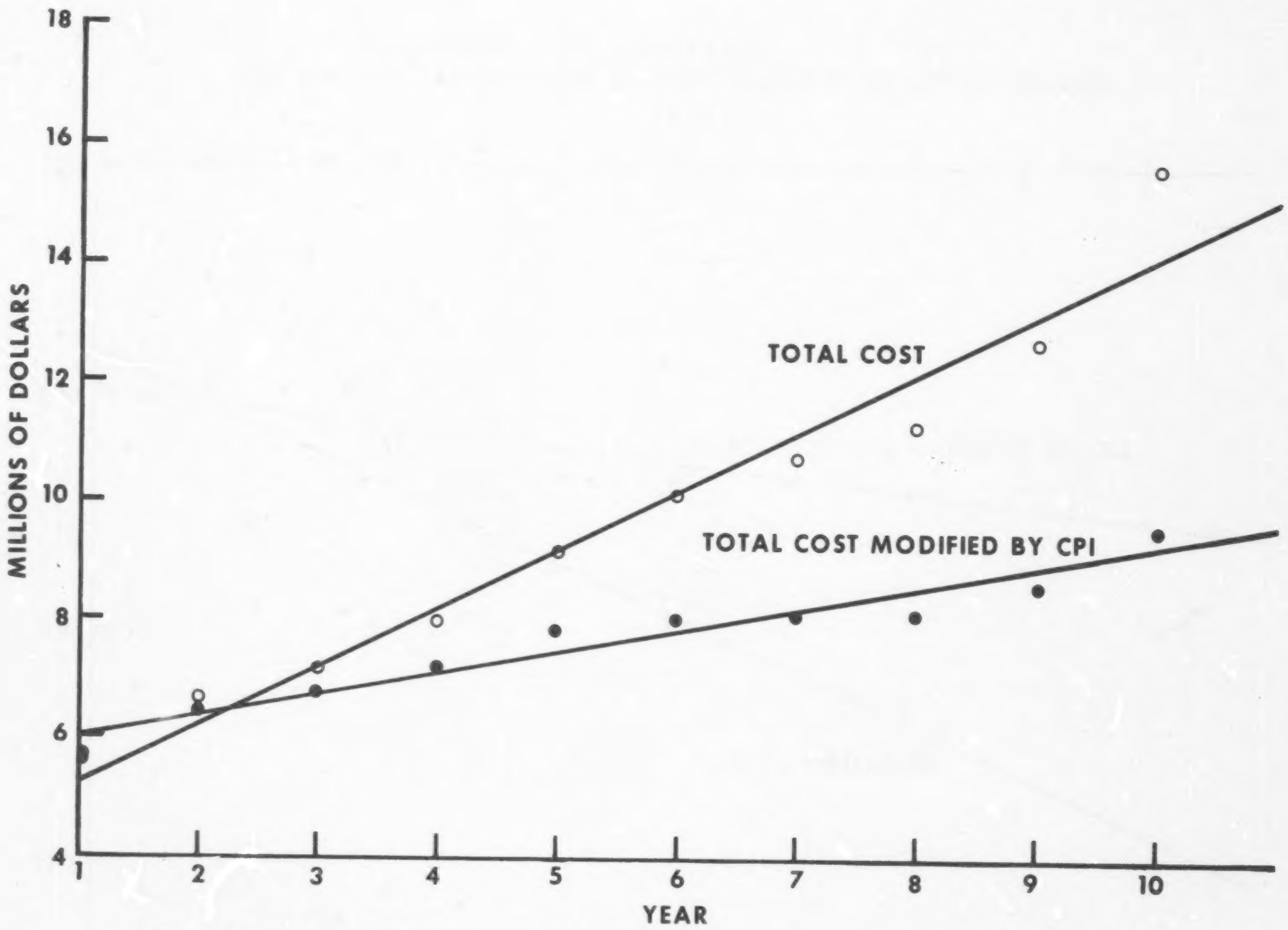

FIG. 42 TOTAL EXPENDITURES FOR ELIZABETHTOWN WATER COMPANY: HISTORICAL AND MODIFIED

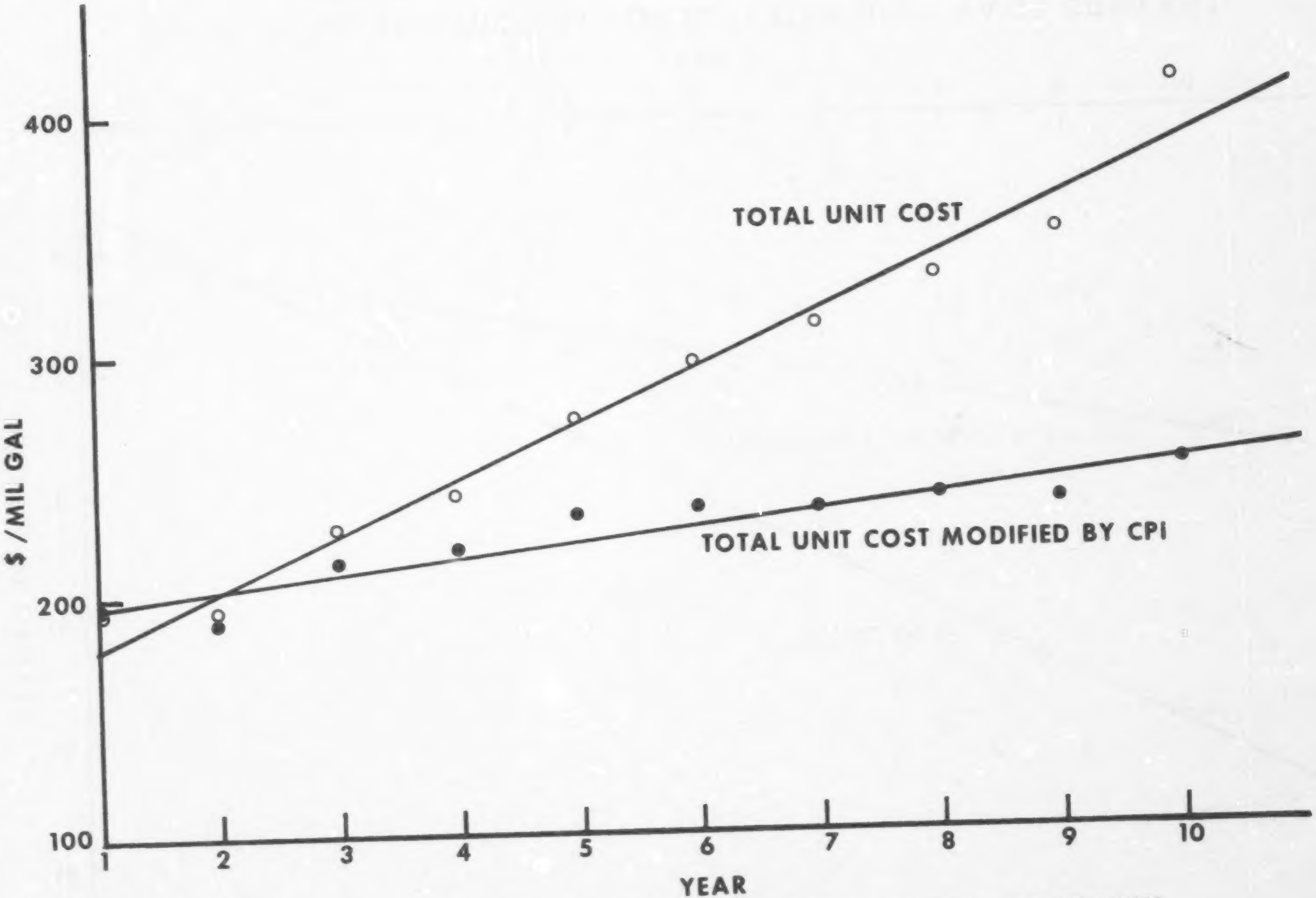

FIG. 43 UNIT COSTS FOR ELIZABETHTOWN WATER COMPANY: HISTORICAL AND CORRECTED

FAIRFAX COUNTY AUTHORITY

The Fairfax County Water Authority, headquartered in Annandale, Virginia, was created under the Virginia Water and Sewage Authority Act of 1950 to supply and distribute water to Fairfax County. The Authority's charter was amended to allow it to provide sewerage services both in and outside of the county, but it cannot levy any taxes or assessments, nor do the obligations of the Authority become obligations of Fairfax County.

Beginning in 1959, the Authority acquired 15 water companies and 22 separate water systems. The Alexandria Water Company, acquired in 1967, serves 70 percent of the Authority's customers -- nearly two-thirds of the population of Fairfax County (364,000), including small areas adjacent to the county. The service area encompasses approximately 400 square miles.

Cost Analysis

Figure 44 illustrates the growth in consumer demand for water over the 10-year period. Rapid growth in billed consumption resulted from the acquisition of new customers. Because accounting problems make it difficult to identify costs according to the functional cost categories mentioned earlier, expenses for the first four years are reported on a total cost basis. From the fifth through the tenth year, costs are identified according to the standardized categories shown in Table 13. Figures 45 through 48 show the changes that have taken place in the operating and capital costs over the period of analysis. Total operating and capital costs over time, corrected by the CPI, are shown in Figures 49 through 51.

Note that unit costs dropped significantly in 1968 with the addition of the Alexandria Water Company to the Authority. This drop in cost reflects some of the economies of scale that may take place when water supplies existing in close proximity band together in a regional water system. The decline in unit prices associated with the addition of Alexander Water Company is due to the averaging into the total cost a system whose operating costs are relatively low due to higher population density.

Systems Analysis

As with the Elizabethtown Water Company, the Fairfax County Water Authority is extremely complex. The system is described in detail in Volume II.

SUMMARY

The five utilities that were selected for analysis are unique, but they illustrate trends or conditions that are typical of many municipal water systems. Kansas City is a classic water system, drawing its water from the river, pumping it through one treatment plant, and distributing it to a widespread service area. Because of the system configuration, it is possible to study cost changes as they occur from the treatment plant to the ends of the system. Kansas City is also fairly stable in water production, with very little increase in revenue-producing water over the 10-year period.

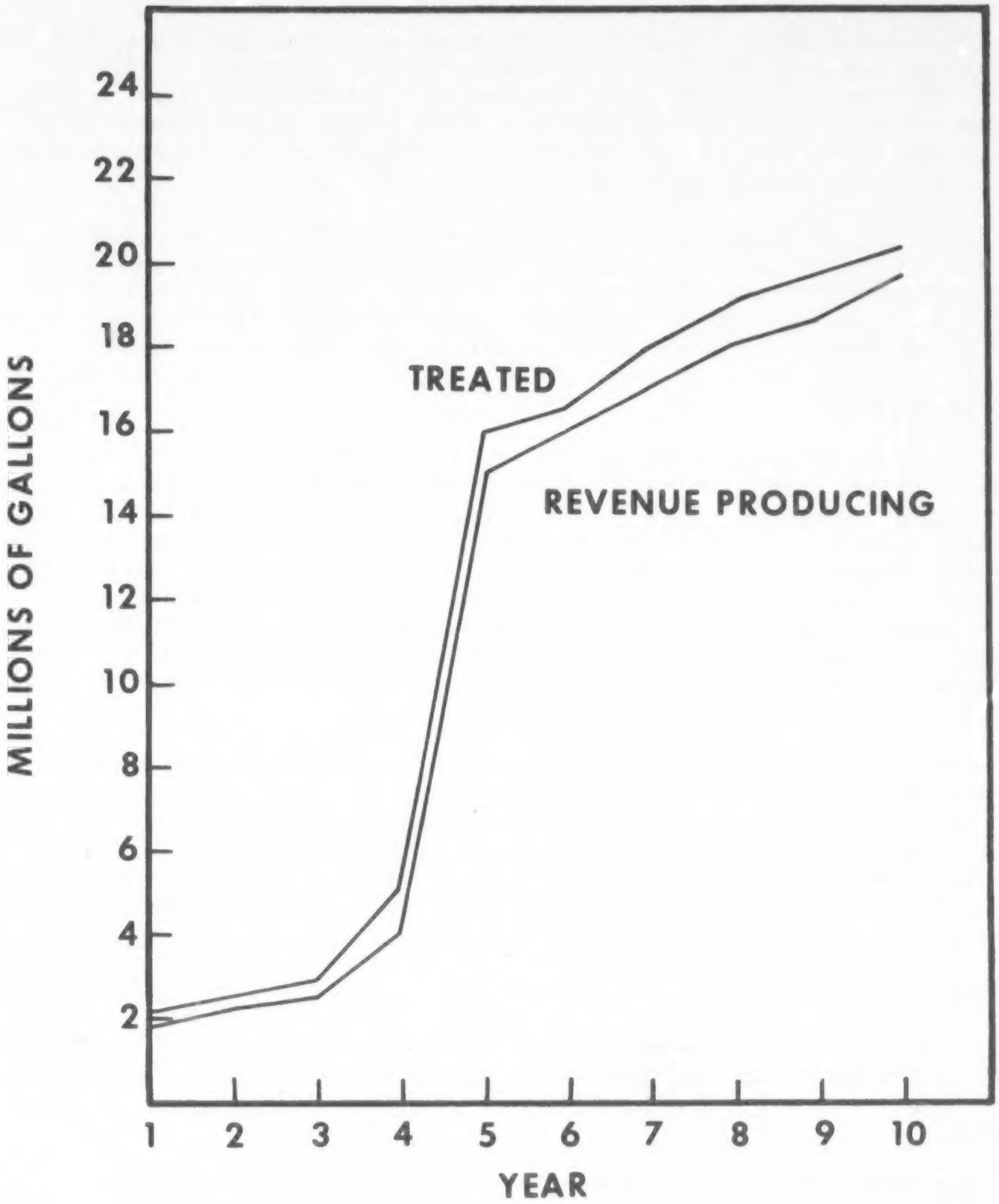

FIG. 44 TREATED AND REVENUE PRODUCING WATER FOR FAIRFAX COUNTY WATER AUTHORITY

TABLE 13. OPERATING AND CAPITAL EXPENDITURES FOR FAIRFAX COUNTY WATER AUTHORITY

Item	Year									
	1	2	3	4	5	6	7	8	9	10
OPERATING COSTS:										
Support services:										
$, in millions	-	-	-	-	0.673	1.000	1.253	1.232	1.406	1.548
% of total	-	-	-	-	29.05	34.60	38.82	35.66	35.72	34.94
$/mil gal	-	-	-	-	45.29	62.43	73.51	70.03	76.00	80.53
Acquisition:										
$, in millions	-	-	-	-	0.150	0.206	0.250	0.289	0.243	0.387
% of total	-	-	-	-	6.48	7.11	7.73	8.36	6.19	8.74
$/mil gal	-	-	-	-	10.11	12.84	14.64	16.42	13.15	10.15
Power and pumping:										
$, in millions	-	-	-	-	0.330	0.384	0.409	0.463	0.528	0.526
% of total	-	-	-	-	14.23	13.28	12.65	13.39	13.41	11.87
$/mil gal	-	-	-	-	22.18	23.97	23.97	26.29	28.53	27.36
Transmission and distribution:										
$, in millions	-	-	-	-	0.702	0.737	0.743	0.918	1.174	1.386
% of total	-	-	-	-	30.29	25.49	23.01	26.55	29.82	31.26
$/mil gal	-	-	-	-	47.22	46.00	43.57	52.16	63.45	72.05
Treatment:										
$, in millions	-	-	-	-	0.462	0.564	0.574	0.555	0.586	0.584
% of total	-	-	-	-	19.93	19.51	17.79	16.04	14.89	13.18
$/mil gal	-	-	-	-	31.07	35.21	33.69	31.51	31.67	30.37
Total Operating Costs:										
$, in millions	0.708	0.834	1.096	1.345	2.317	2.891	3.229	3.456	3.938	4.432
$/mil gal	397.92	402.22	451.57	340.57	155.87	180.45	189.38	196.38	212.80	230.46

TABLE 13 (Continued). OPERATING AND CAPITAL EXPENDITURES FOR FAIRFAX COUNTY WATER AUTHORITY

	Year									
Item	1	2	3	4	5	6	7	8	9	10
CAPITAL COSTS:										
Depreciation ($, in millions)	0.234	0.234	0.241	0.912	1.584	1.584	1.584	1.584	1.584	1.587
Interest ($, in millions)	0.608	0.663	0.663	0.663	4.800	3.401	4.935	4.105	4.060	4.011
Total capital cost ($, in millions)	0.842	0.897	0.904	1.575	6.384	4.985	6.519	5.689	5.644	5.598
Total operating and capital cost:										
$, in millions	1.550	1.782	2.000	2.921	8.701	7.876	9.748	9.146	9.581	10.030
$/mil gal	871.48	810.36	823.90	739.41	585.29	491.64	571.73	516.74	517.79	521.55

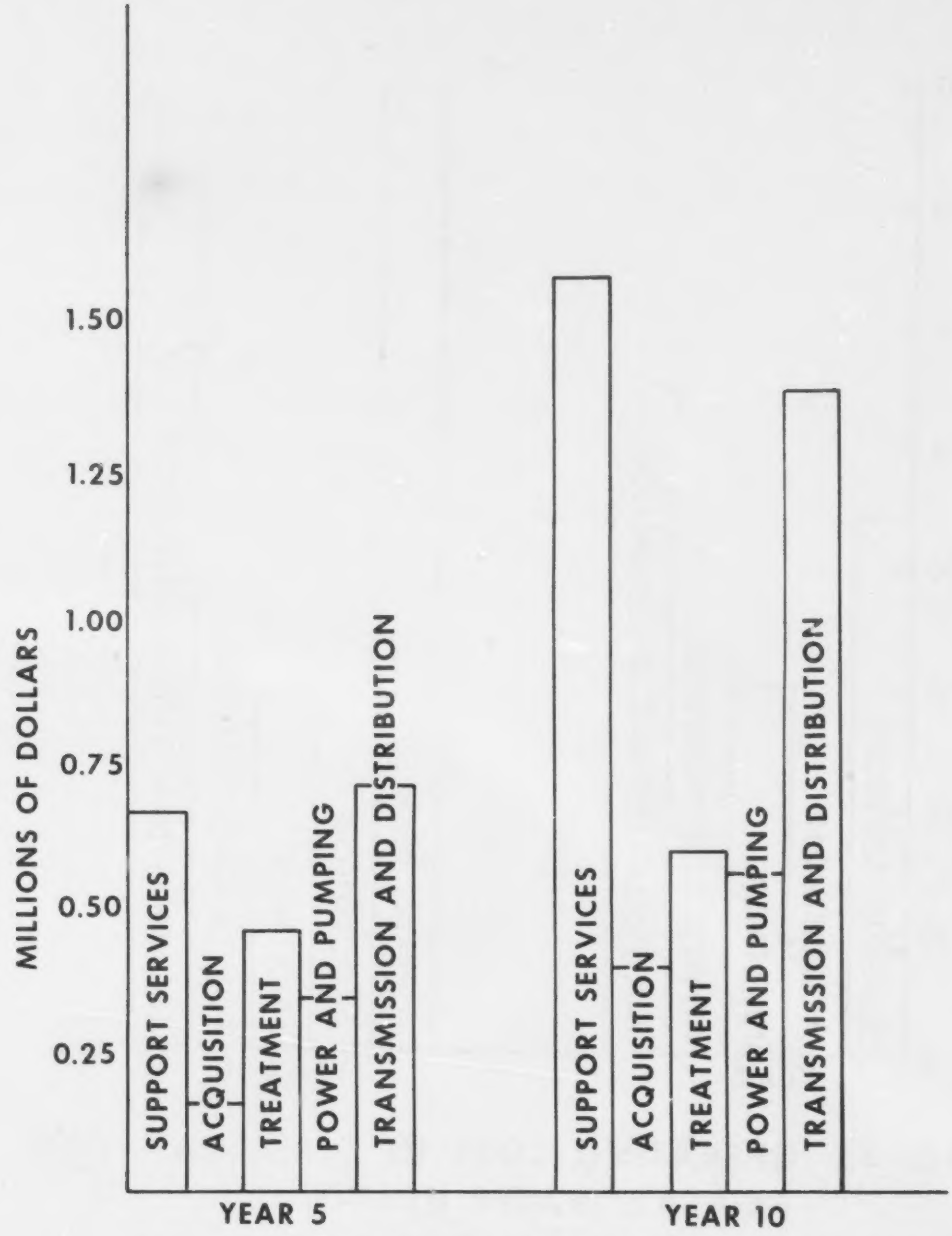

FIG. 45 OPERATING COSTS FOR FAIRFAX COUNTY WATER UTILITY

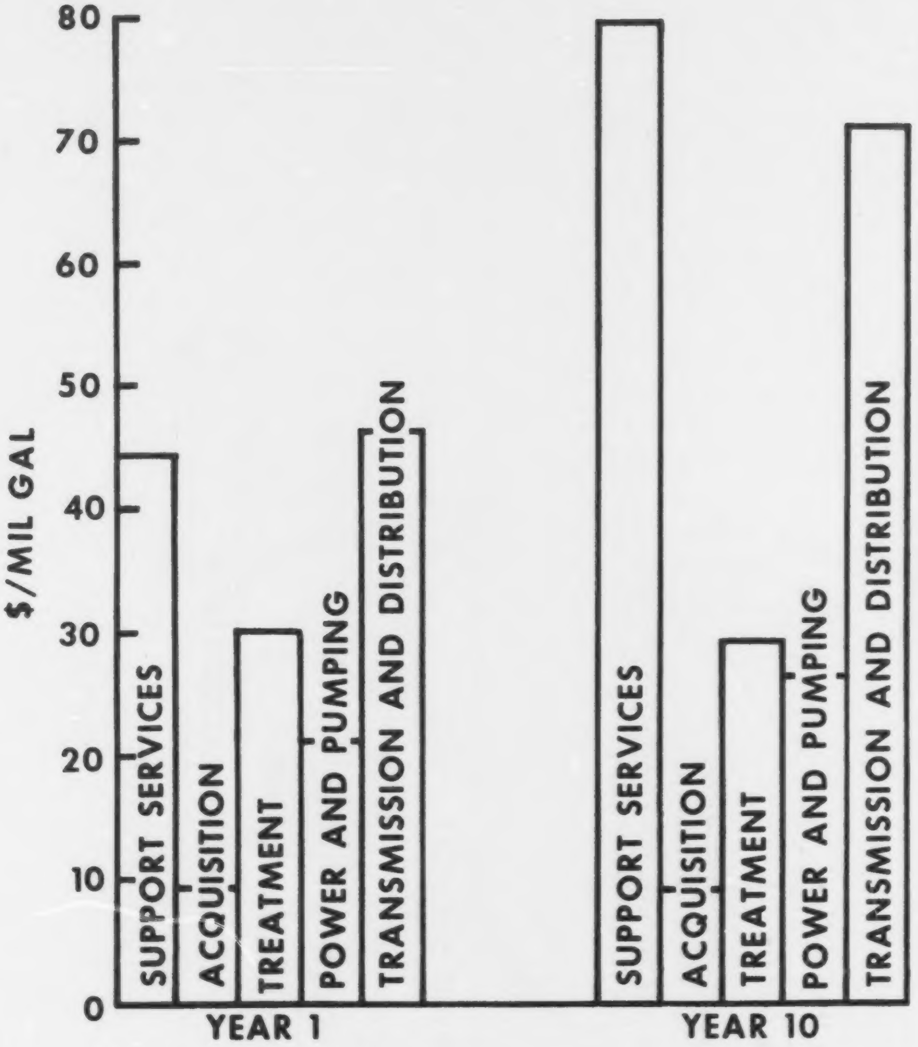

FIG. 46 OPERATING COST IN $/MIL GAL FOR FAIRFAX WATER UTILITY

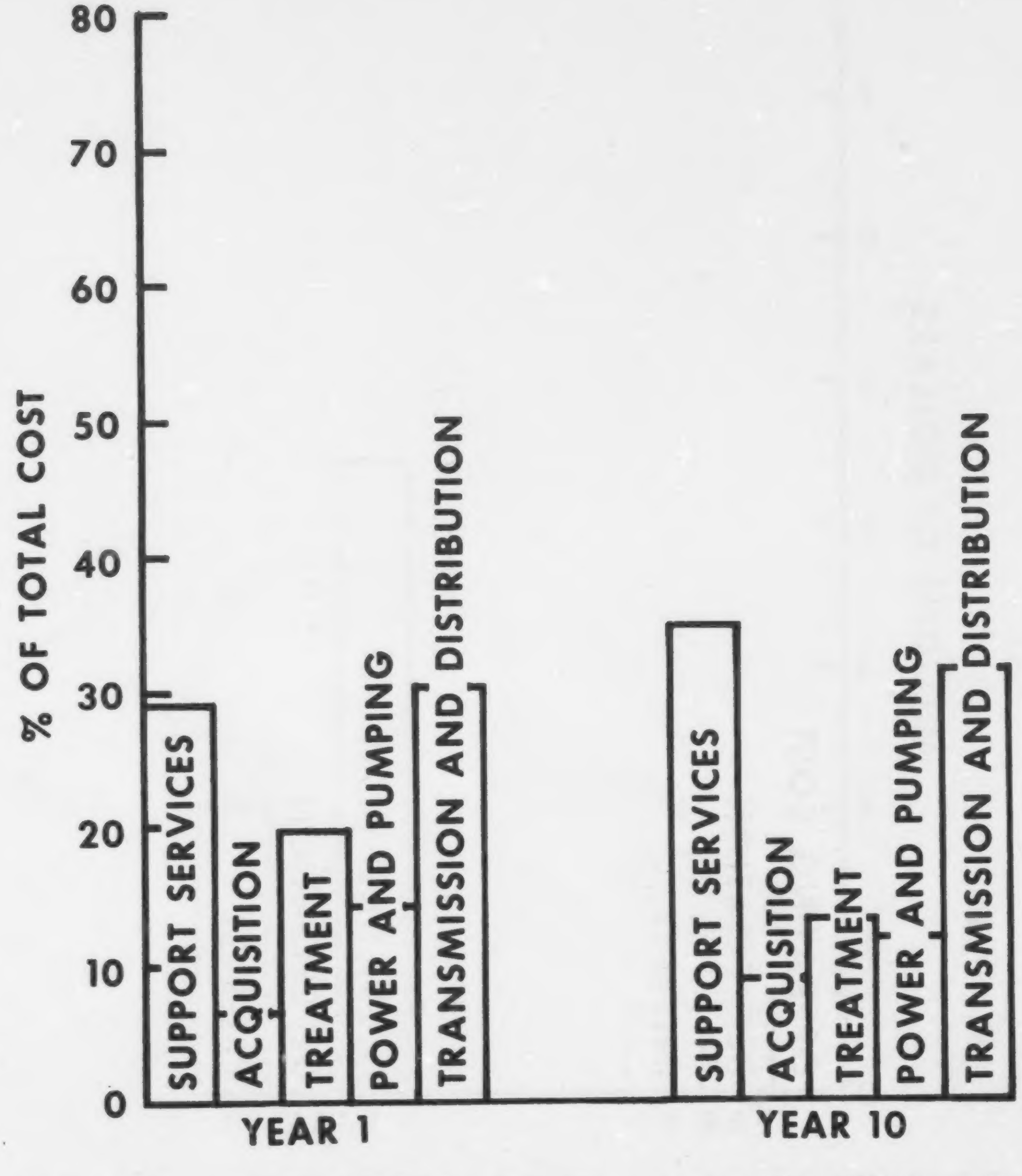

FIG. 47 OPERATING COST AS A PERCENT OF TOTAL COST FOR FAIRFAX WATER UTILITY

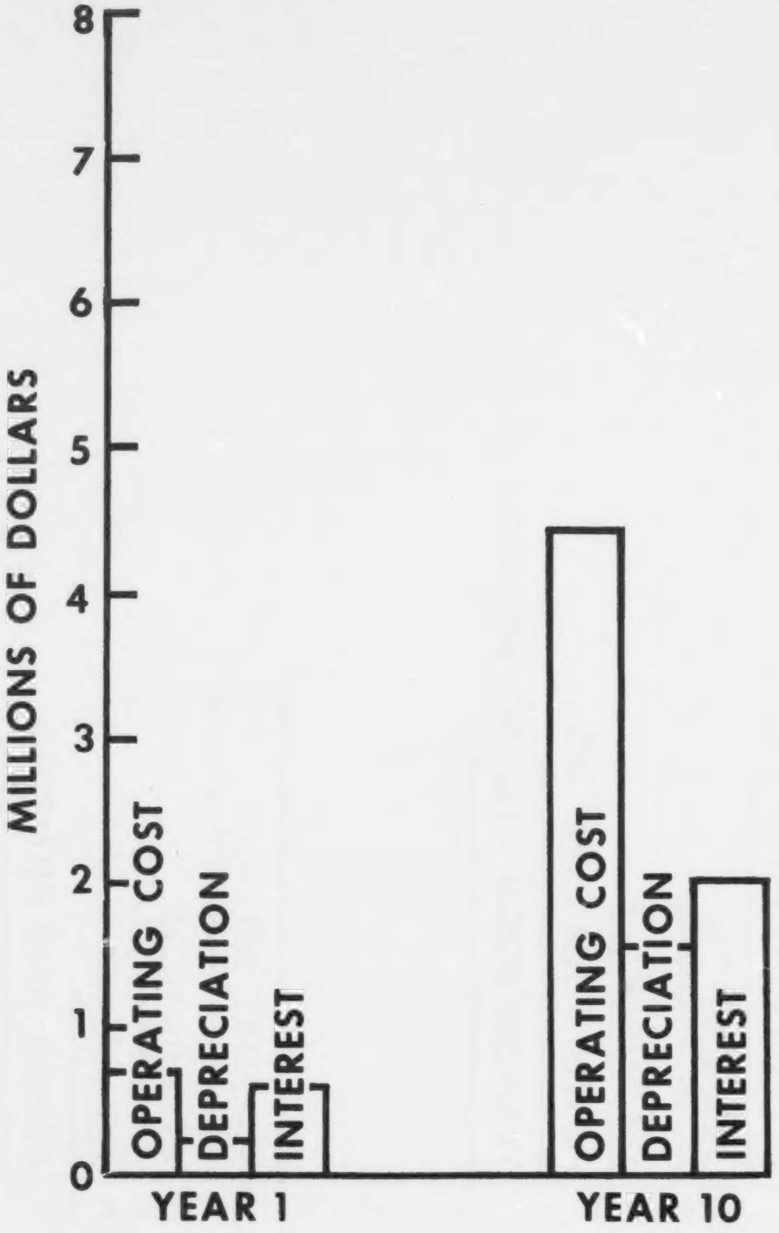

FIG. 48 OPERATING AND CAPITAL COSTS FOR FAIRFAX WATER UTILITY

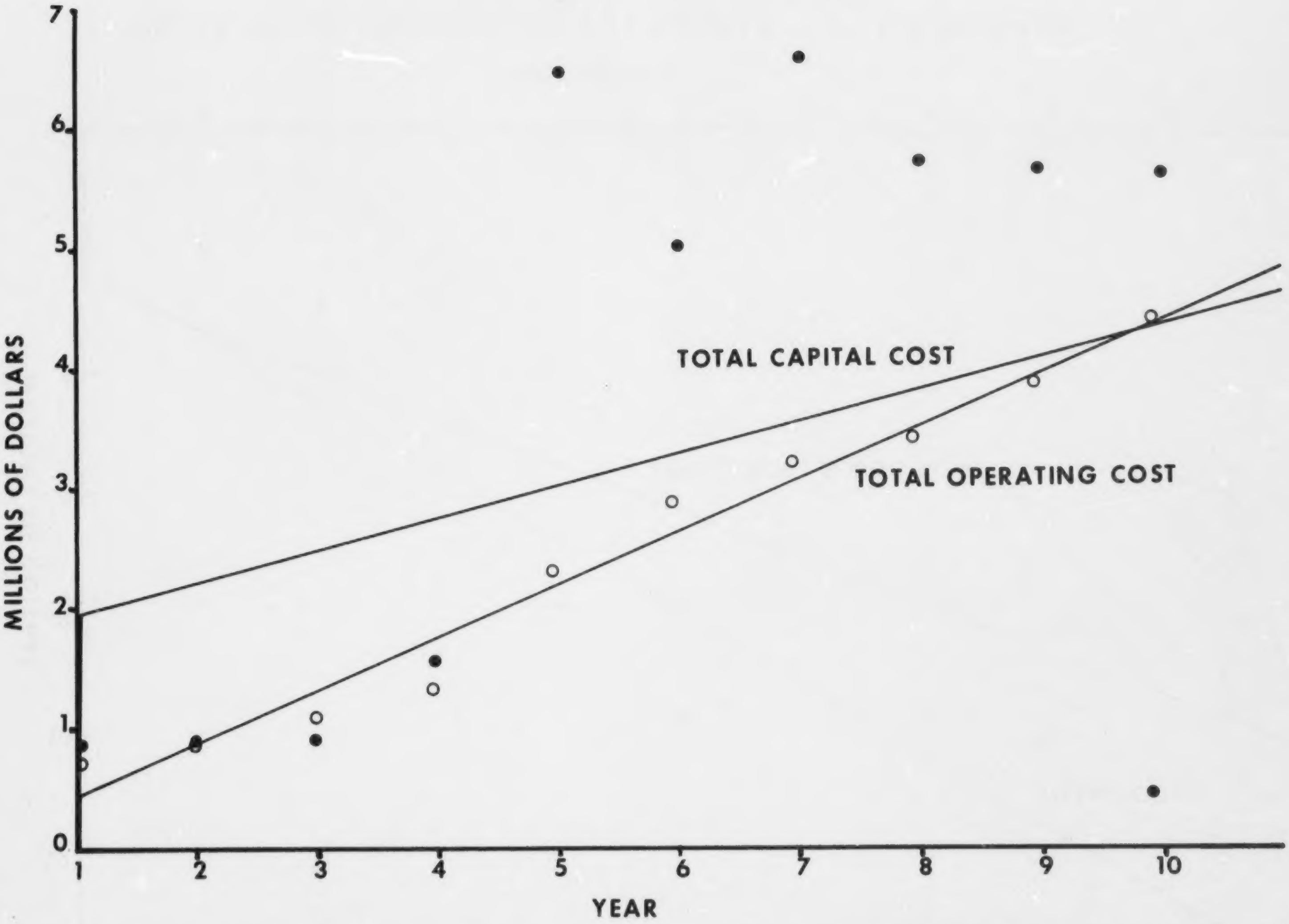

FIG. 49 OPERATING AND CAPITAL EXPENDITURES FOR FAIRFAX WATER AUTHORITY

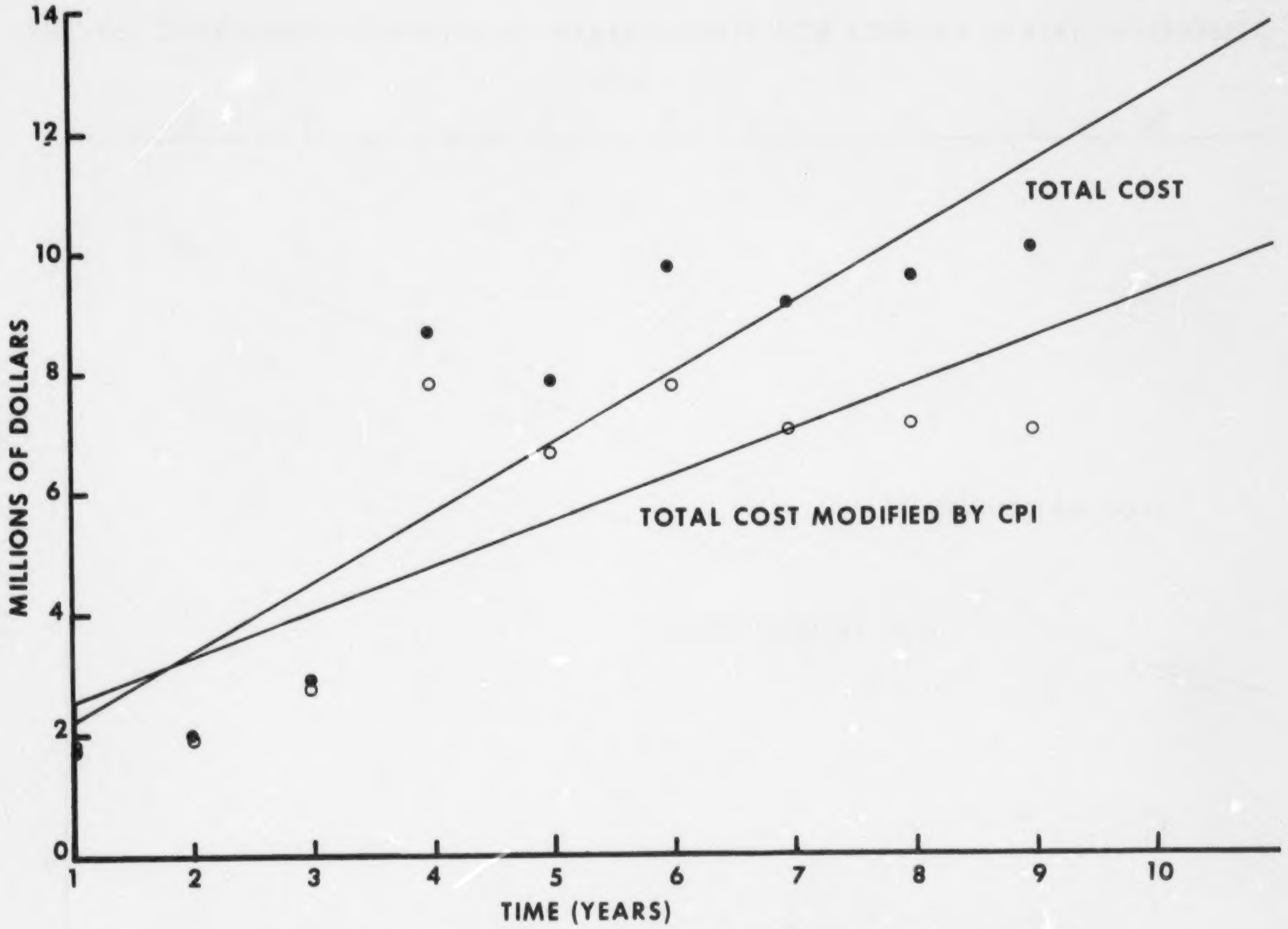

FIG. 50 TOTAL EXPENDITURES FOR FAIRFAX WATER AUTHORITY: HISTORICAL AND MODIFIED

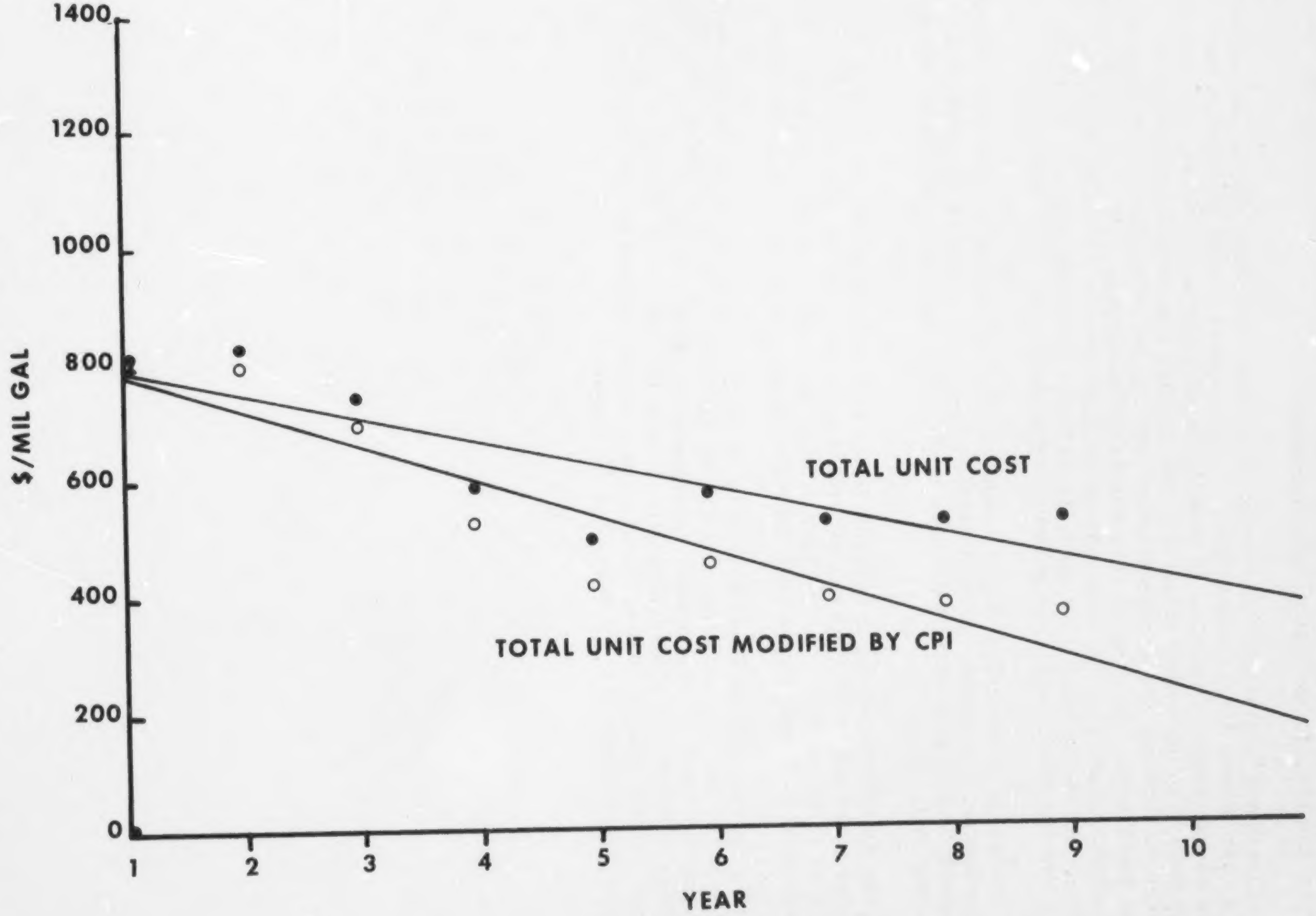

FIG. 51 UNIT COST FOR FAIRFAX WATER AUTHORITY: HISTORICAL AND MODIFIED

Inflationary pressures have caused the unit costs, even when corrected for time by the CPI, to exhibit steady increases.

Cincinnati's distribution system is similar to Kansas City's and allows for a cost versus distance analysis. In Cincinnati, water production has increased steadily, resulting in stabilized unit costs for water. Corrected costs have even decreased slightly. The utility has extensive records for capital investment, and a reproduction cost can be calculated for the waterworks facilities. Results of this analysis demonstrate that over the life of the utility, the value of its capital facilities have increased fivefold. A labor cost and productivity analysis reflects that the increase in labor costs has not been completely balanced by increases in labor productivity.

Dallas is a rapidly growing community with an extensive reservoir system. By continuously expanding the acquisition system and ringing the city with treatment facilities, water shortages have been eliminated, and water costs have been held down.

The Elizabethtown Water Company is an investor-owned utility and as such has a totally different set of problems as compared to publicly-owned utilities. For example, in the last year of analysis, the Elizabethtown utility paid $4.6 million in real property taxes, or 27% of its total costs.

The Fairfax County Water Authority is rapidly growing by acquiring new customers through the purchase of existing utilities. It represents extreme economies of scale in its capital investments program. Interest costs are much more significant for Fairfax County than for the other utilities because of their recent acquisition of facilities. In the following section, comparisons of these items will be made in more detail.

SECTION 5

UTILITY COST COMPARISONS

In this section, cost trends among the various utilities are examined simultaneously.

Figure 52 illustrates the steady increase in revenue-producing water over the 10-year period for the five utilities. The average yearly increase was approximately 5%. Consumption for the Cincinnati, Elizabethtown Water Company, and Kansas City utilities had a lower growth rate than did the consumption for Dallas and the Fairfax County Water Authority.

Dallas' growth is due to demand by the small communities located within Dallas County but outside the city. Should this demand level off, Dallas' water production will probably be similar to that of the Cincinnati, Elizabethtown, and Kansas City utilities.

Water production by the Fairfax County Water Authority has had four- and five-year periods of slightly greater than average growth, separated by a one-year period of very rapid growth because of acquisition of the Alexandria Water Company's source of supply, treatment facilities on Occoquan Creek, and the associated service area. This acquisition occurred during the fourth year of the data analysis period. Growth during the other years is due to smaller additions to the system.

Cost of Supply

Figure 53 shows unit costs for five utilities. Four of the utilities (Cincinnati, Elizabethtown Water Co., Dallas, and Kansas City) exhibit increases in cost of about 5% a year because of increased prices for power, labor, chemicals, and other items. The Fairfax County Authority unit costs have decreased as a result of the rapid expansion in consumption (Figure 52). Heavy investments in capital in a short time span combined with a rapid expansion in production has reduced costs sharply. Despite these reductions, the cost of Fairfax County water is higher than that of any of the other four utilities.

Figure 54 shows that Elizabethtown Water Co., Cincinnati, and Kansas City have relatively constant operating expenditures as a percent of total cost. For the entire 10-year period, operating cost has been 75% to 85% of total cost. Dallas and Fairfax have maintained lower percentages. In Dallas, 60% to 65% of the costs are operating expenses. In Fairfax, 32% of the expenditures are operating costs. These wide variations occurred as a result of

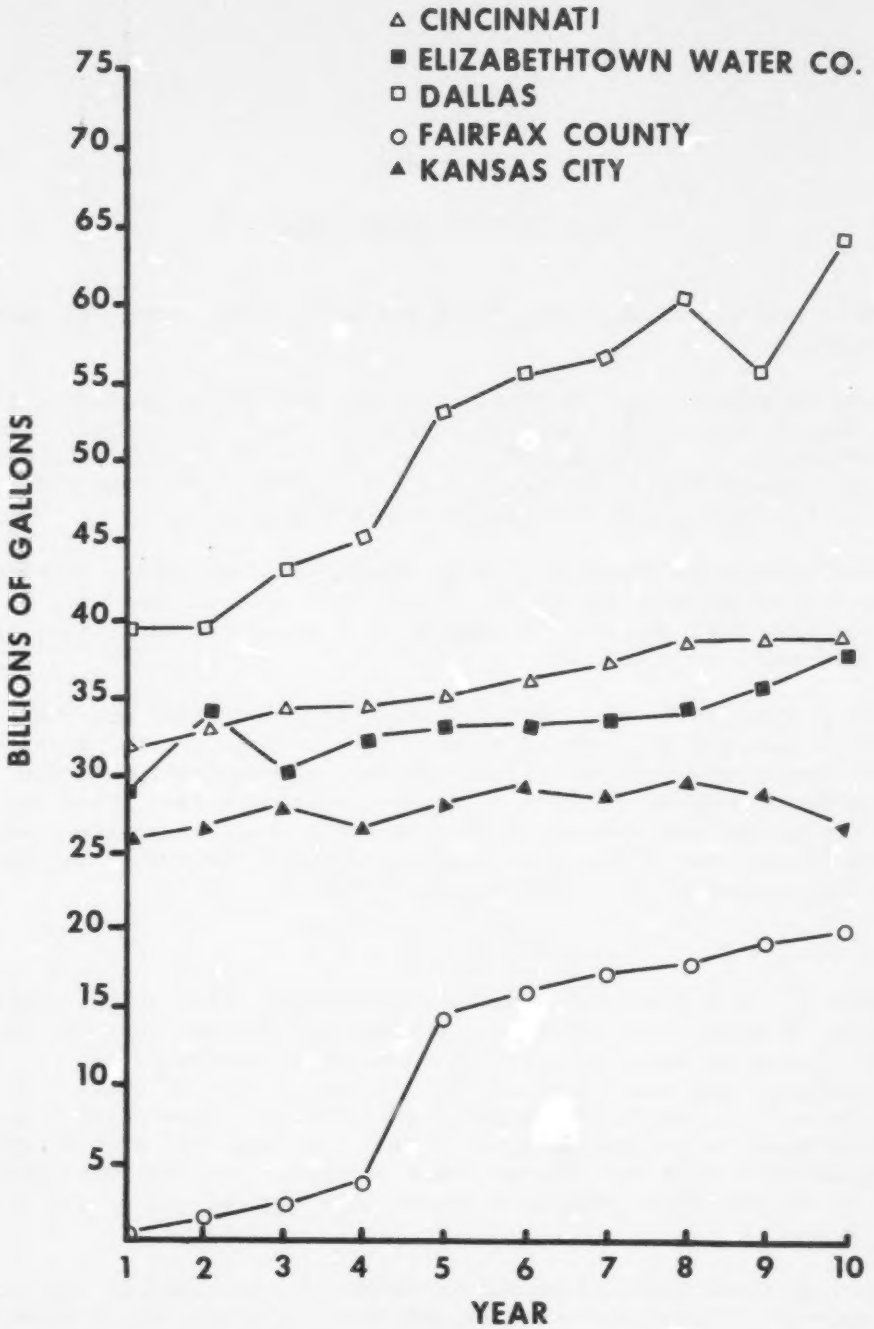

FIG. 52 REVENUE PRODUCING WATER FOR FIVE UTILITIES

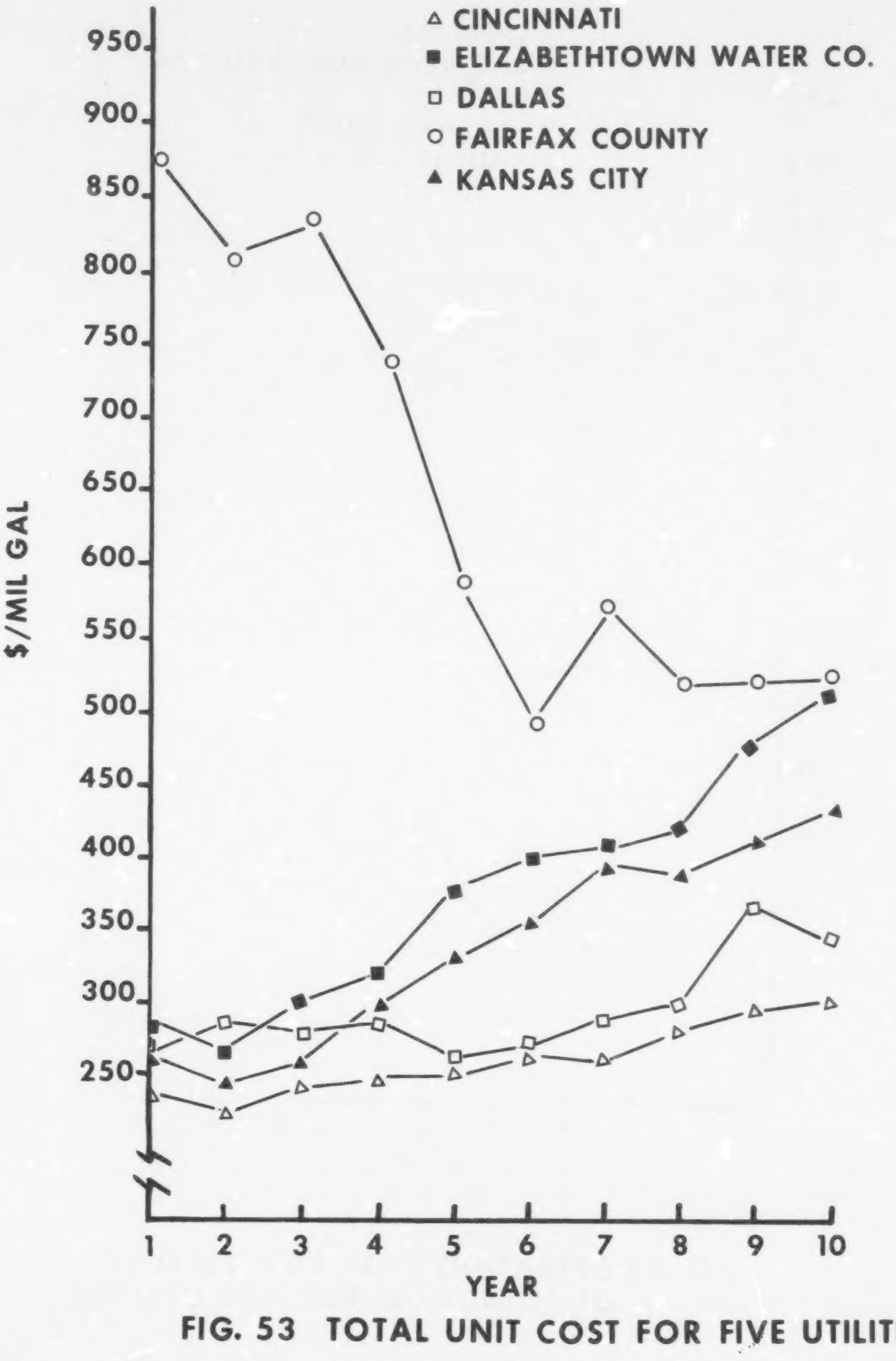

FIG. 53 TOTAL UNIT COST FOR FIVE UTILITIES

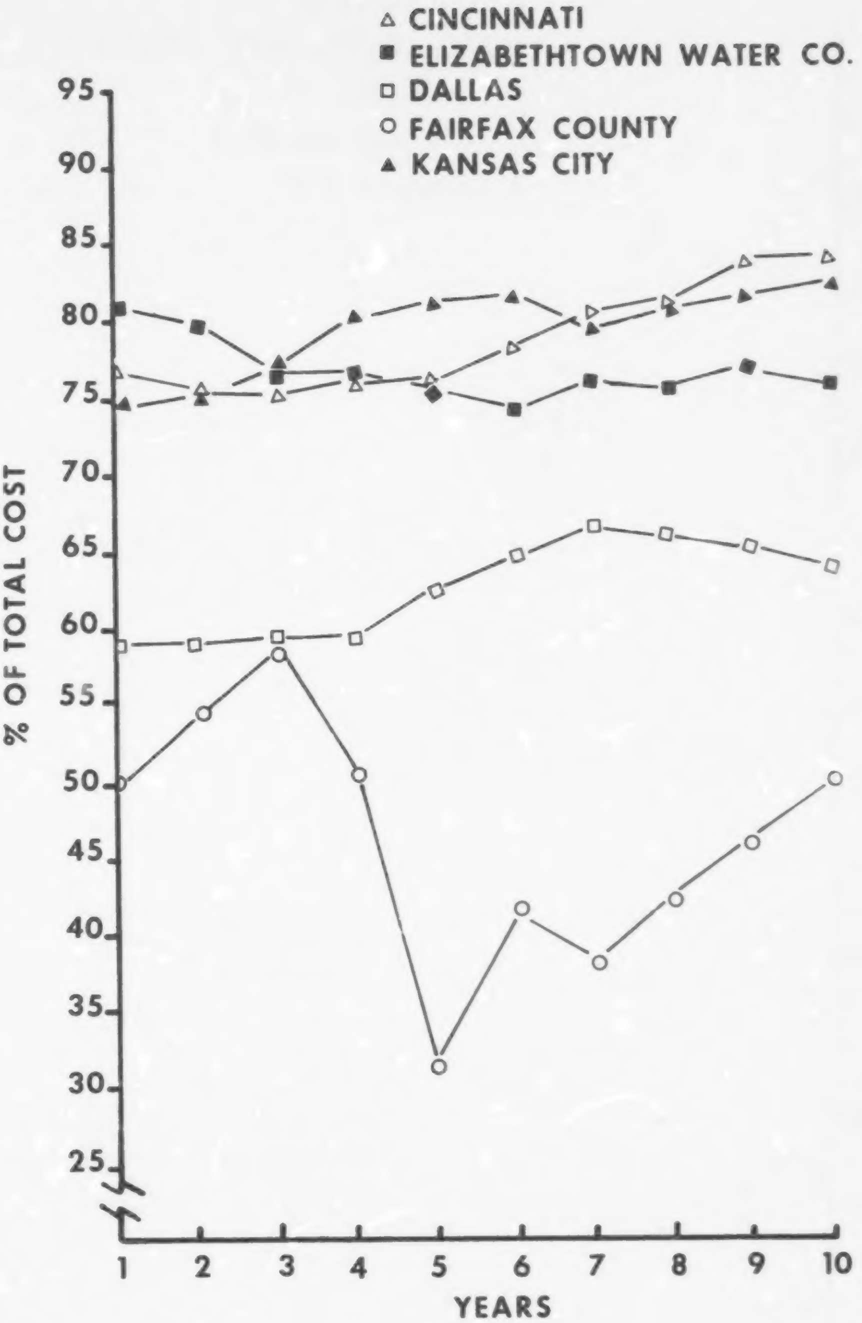

FIG. 54 OPERATING COST AS A PERCENT OF TOTAL COST FOR FIVE UTILITIES

the different characteristics of the utilities studied. Elizabethtown Water Co., Cincinnati, and Kansas City are stable utilities with either no increase or small steady increases in demand for water. Capital investment is primarily utilized for capital improvements of the existing system with limited investment in new facilities. Dallas is a more rapidly growing utility, and Fairfax is a smaller utility that has dramatically increased its water production in 10 years. In order to increase water production at these rates, rapid investment in capital is required thereby reducing the operating expenditures as a percent of total cost. As Dallas and Fairfax County utilities achieve stabilization, their expenditure patterns will be similar to those of the other older utilities.

Figure 55 shows unit costs for treatment. Kansas City, with the highest treatment cost, has also experienced the most rapid increase in unit cost over the 10-year period. Kansas City's treatment plant draws water from the Missouri River. Details of the treatment process, including lime softening, are described in Volume II. Most of the rapid rise in cost is due to increases in chemical and labor costs. Figure 55 shows that Dallas and Elizaabethtown have also had substantial increases in treatment costs.

Labor-Related Costs

Figures 56, 57, and 58 illustrate labor cost trends for the five water utilities. Labor rates (Figure 56) have increased by about 8% a year. The number of man-hours/mil gal of revenue-producing water (Figure 57) has decreased about 2% a year. Productivity rates vary widely; the Elizabethtown Water Company produces water with fewer than 15 man-hours/mil gal, and the Fairfax County Authority produces water with 22 to 27 man-hours/mil gal; the other utilities require more total man-hours/mil gal.

Figure 58, total payroll costs/mil gal, is a function of the labor rate and productivity. Cincinnati, Elizabethtown, Dallas, and Kansas City show an increase of approximately 6%/year. Fairfax County experienced a sharp decrease during the two years when revenue-producing water increased drastically.

Figure 59 shows support services as a percent of total operating cost, including all administrative, accounting, meter reading and billing, and engineering functions. These costs range from 23% to 45%.

First and Last Year Cost Comparisons

Figures 60 and 61 show sharp contrasts in allocation of costs to support services, acquisition, treatment, power and pumping, and transmission and distribution. Fairfax County is not included in these figures because cost data were not available for the full 10-year period.

Figure 60 shows the total dollars increased in every category, with the greatest increase occurring in support services. Figure 61 shows the same breakdown of operating cost categories as a percent of total operating cost. Support services increased as a percent of total, acquisition remained the

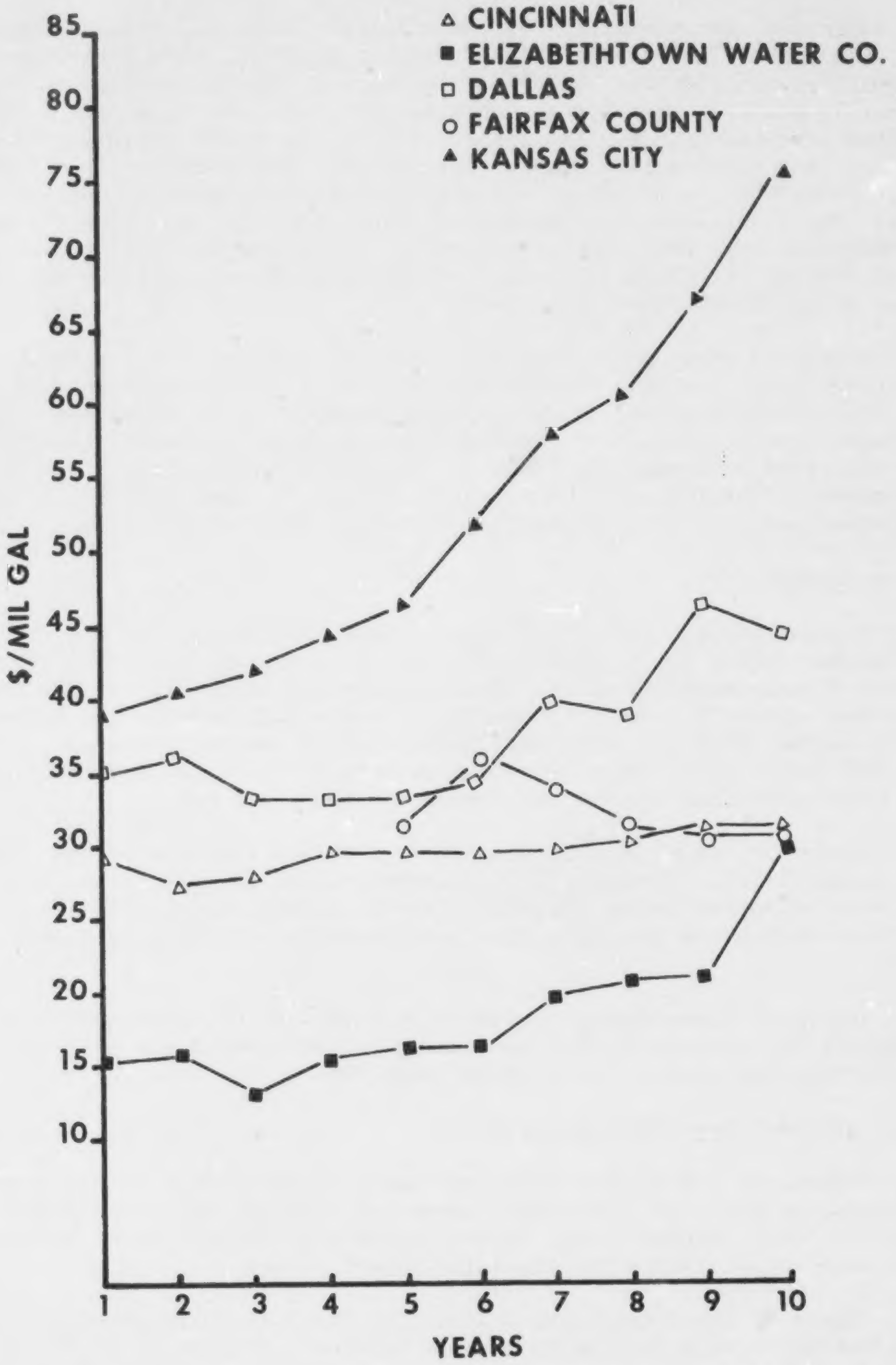

FIG. 55 UNIT TREATMENT COSTS FOR FIVE UTILITIES

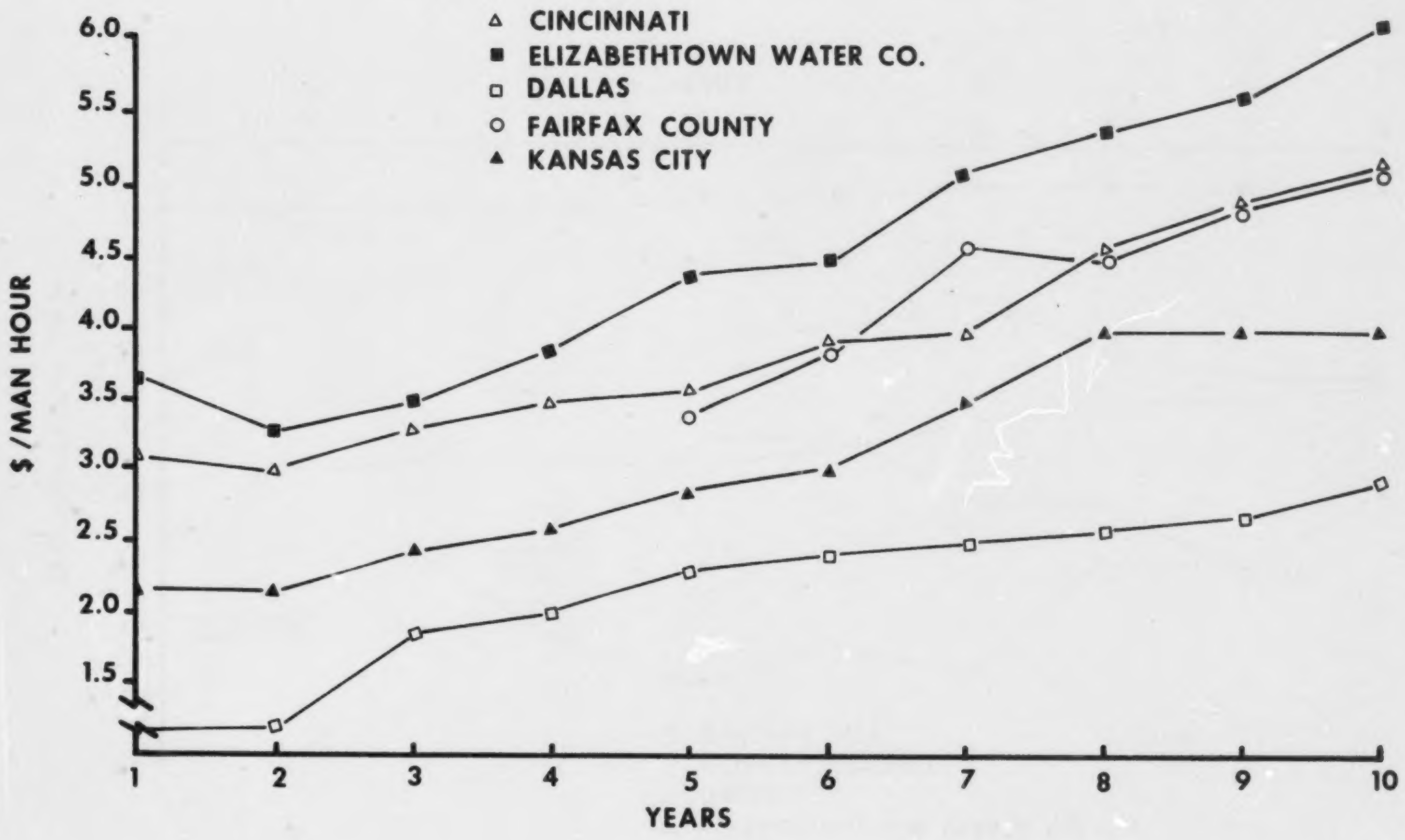

FIG. 56 PAYROLL IN DOLLARS/MAN HOUR FOR FIVE UTILITIES

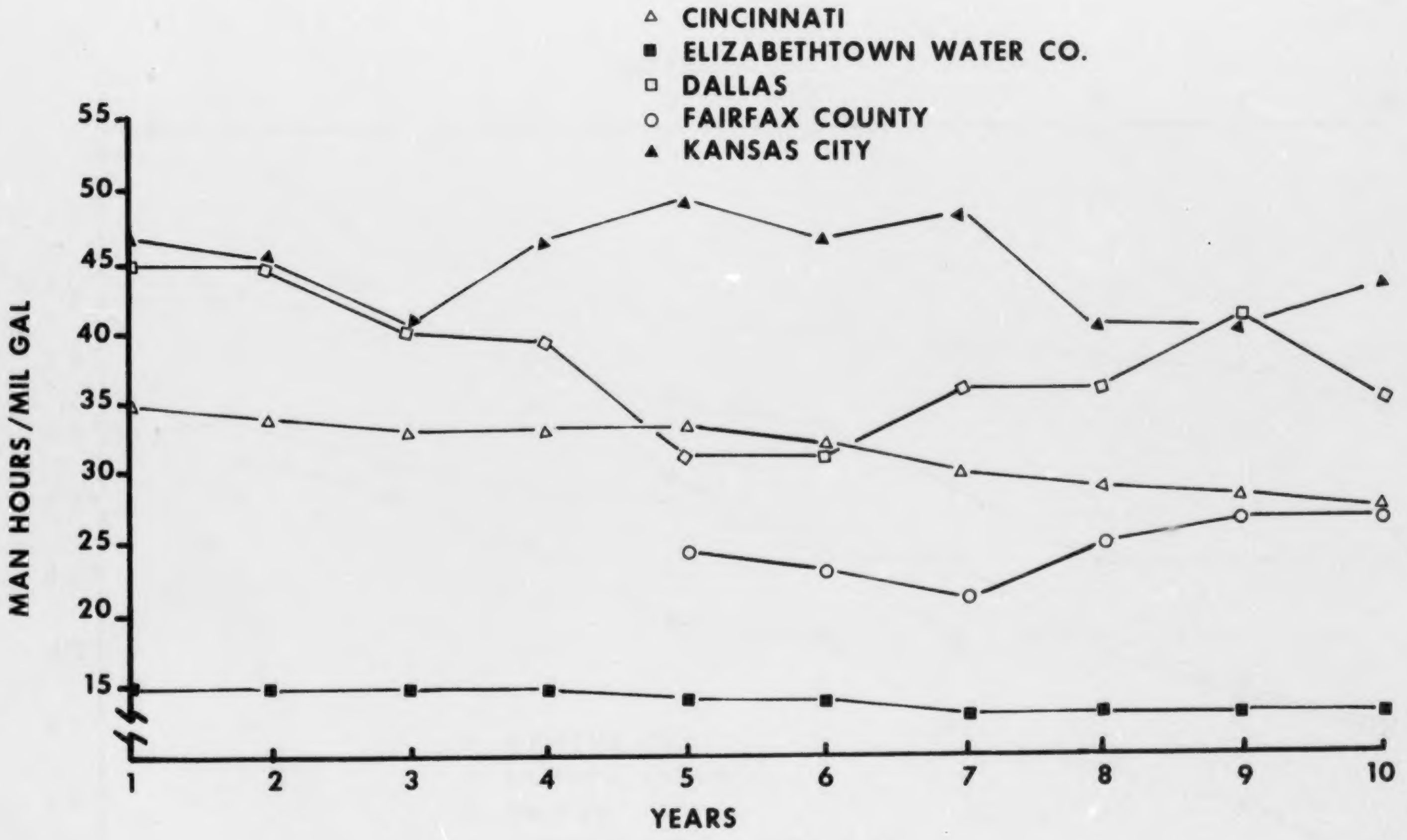

FIG. 57 MANHOURS/MIL GAL FOR FIVE UTILITIES

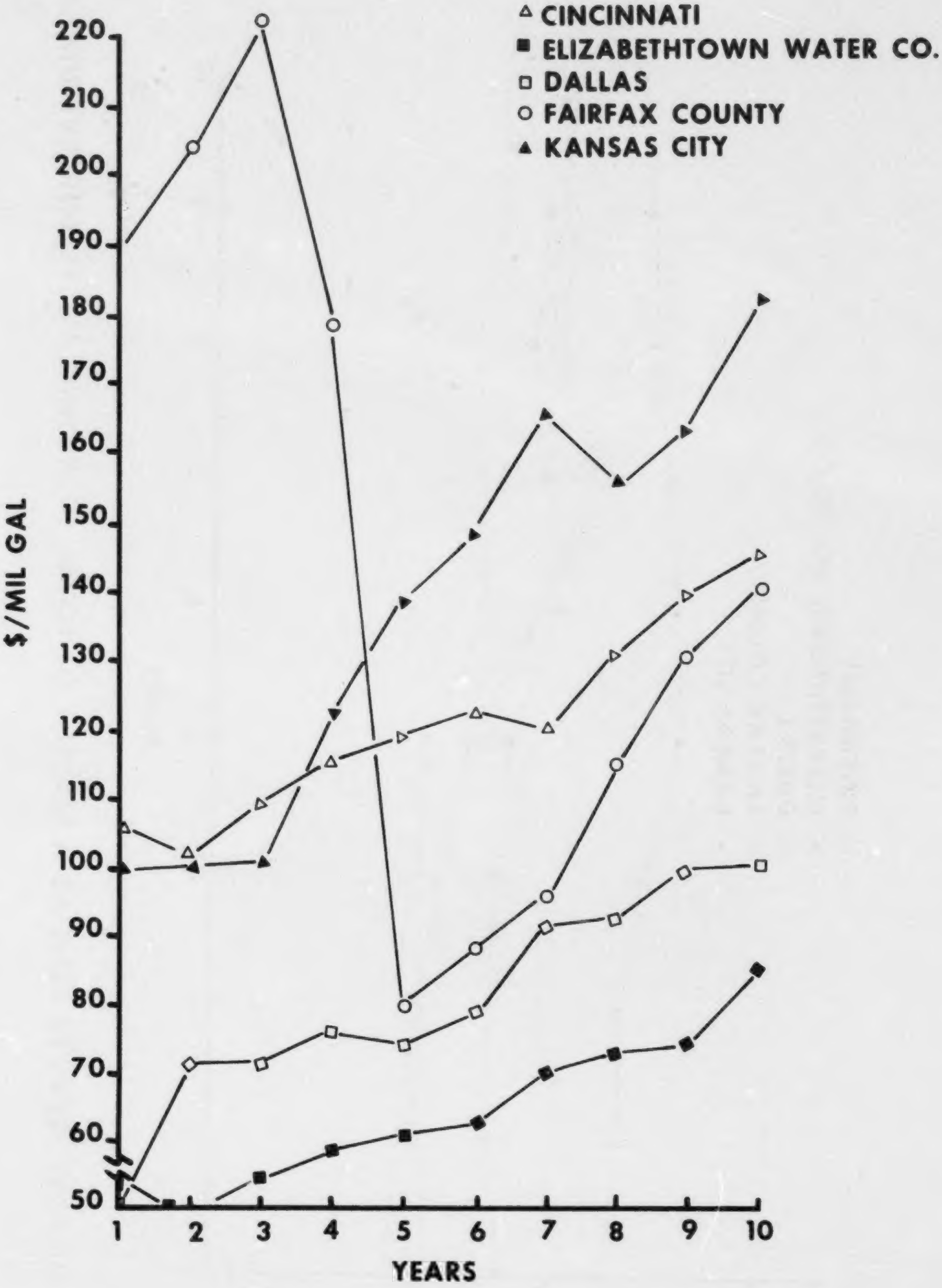

FIG. 58 PAYROLL/MIL GAL FOR FIVE UTILITIES

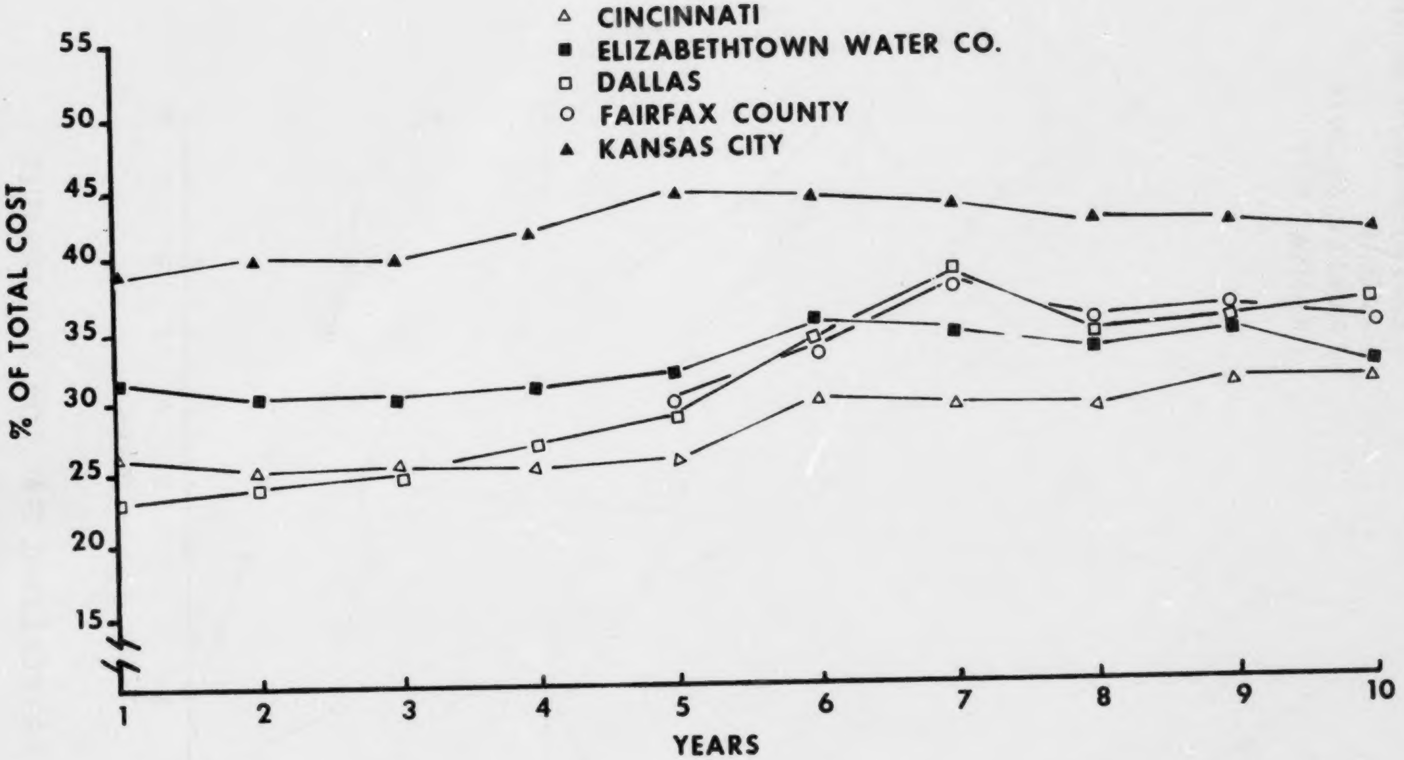

FIG.59 SUPPORT SERVICES COST AS A PERCENT OF TOTAL OPERATING COSTS FOR FIVE UTILITIES

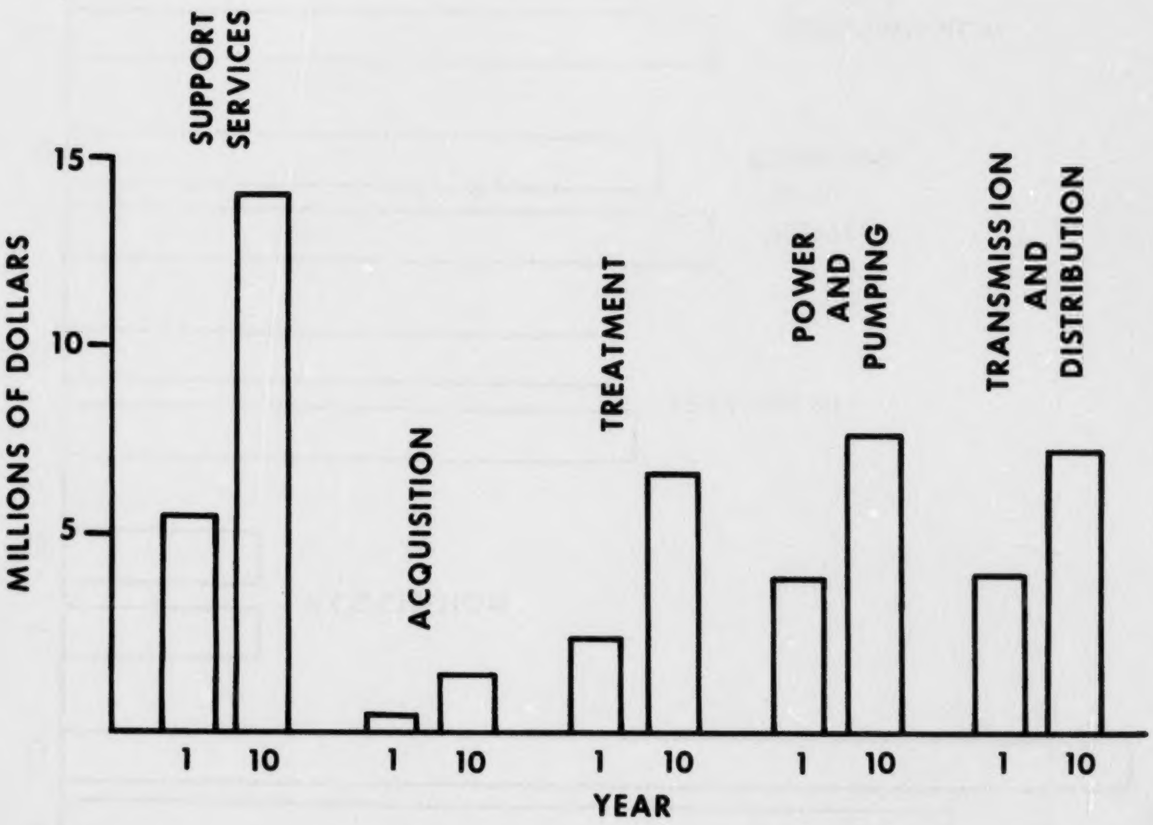

FIG.60 AVERAGE OPERATING COSTS FOR FIVE UTILITIES: BY CATEGORY

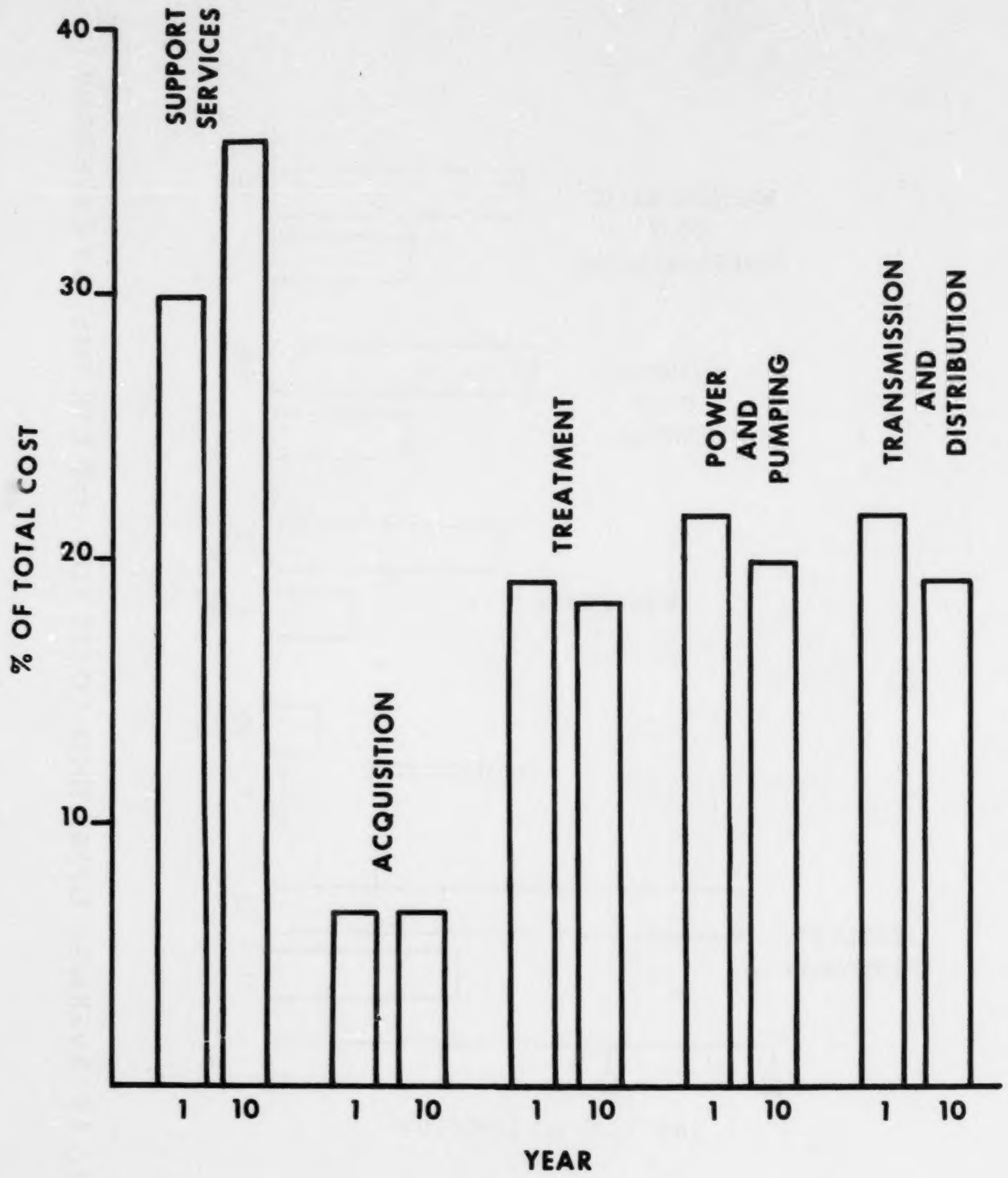

FIG. 61 UTILITY OPERATING COSTS: PERCENT OF TOTAL

same, and the other three categories (treatment, power and pumping, and transmission and distribution) decreased over the 10-year period.

Summary of Results

As the data from these five utilities show, water supply costs are increasing as a result of labor and material cost increases. A moderating effect is due to increased productivity. Many of the increases are related to increased demand for water. The following section analyzes these costs in aggregate.

SECTION 6

AGGREGATE ANALYSIS

As the previous limited data analysis shows, certain key variables exhibit trends that can and should be analyzed. Therefore, averages of the data from all 12 utilities for specific variables have been constructed. The variables considered are as follows: revenue-producing water in billions of gallons, total operating cost, total capital cost, interest paid/year, depreciation/year, support services, acquisition, treatment, power and pumping, distribution, chemical cost, man-hours, man-hours/mil gal, payroll, dollars/man-hour, unit operating costs, unit capital cost, and total unit cost for production of water.

Table 14 summarizes the average costs associated with operating and capital expenditures over the 10-year period for all the utilities studied. Average expenditures increased by 110% over the period, but unit costs increased by only 25%.

Figure 62 shows the average revenue-producing water over the 10-year period. There has been a continuous upward trend in revenue-producing water, increasing from 23 billion gallons in 1965 to 32.1 billion gallons in 1974.

Figure 63 shows that the average operating expenditures have increased more rapidly than have capital expenditures. Operating costs increased by 127%, while capital costs increased by 78%.

Figure 64 shows the increases that have taken place in support services, acquisition, and treatment costs. Figure 65 shows the cost increases for transmission and distribution, and power and pumping over the period of analysis. Support services costs are obviously increasing at a much faster rate than other categories, although the increases in cost for power and pumping from 1972 through 1974 have been dramatic.

Figure 66 shows the increases over time for energy and chemical costs, and Figure 67 shows the same variables versus revenue-producing water. The relationship assumed in these two figures is linear, but it can be seen that energy costs are going up at a nearly exponential rate in recent years. Energy costs are increasing faster than chemical costs. Because support services is labor intensive, it is worthwhile to examine the labor portion of the costs. Manpower costs and labor productivity are therefore summarized in Table 15. The relationship between payroll and operating costs is shown in Figure 68. Figure 69 shows the relationship between labor wage rate and

TABLE 14. AVERAGE OPERATING AND CAPITAL COSTS FOR ALL FIVE UTILITIES OVER THE 10-YEAR STUDY PERIOD

Item	Years									
	1	2	3	4	5	6	7	8	9	10
OPERATING COSTS:										
Support services:										
$, in millions	1.126	1.198	1.474	1.560	1.837	2.031	2.268	2.437	2.705	3.127
% of total	26.0	26.4	29.7	30.2	31.6	32.4	31.6	31.5	31.7	31.1
$/mil gal	55.29	54.60	62.51	61.89	71.66	76.19	79.35	83.49	91.72	89.98
Acquisition:										
$, in millions	0.981	1.007	0.978	1.062	1.231	1.289	1.537	1.770	1.990	2.356
% of total	22.7	22.2	19.7	20.6	21.2	20.5	21.4	22.9	23.3	23.5
$/mil gal	48.27	45.91	41.46	42.22	48.08	48.20	53.75	60.69	67.42	67.43
Treatment:										
$, in millions	0.539	0.577	0.617	0.630	0.701	0.783	1.013	0.913	0.998	1.212
% of total	12.5	12.7	12.4	12.2	12.1	12.5	14.1	11.8	11.7	12.1
$/mil gal	26.58	26.27	26.10	25.0	27.44	29.39	35.41	29.63	33.85	35.01
Power and pumping:										
$, in millions	0.789	0.830	0.922	0.870	0.933	0.955	1.042	1.172	1.294	1.805
% of total	18.2	18.3	18.5	16.8	16.1	15.2	14.5	15.2	15.2	18.0
$/mil gal	38.70	37.85	38.94	34.43	36.51	35.74	36.42	40.29	43.98	52.08
Transmission and distribution:										
$, in millions	0.890	0.927	0.978	1.044	1.108	1.213	1.320	1.439	1.548	1.541
% of total	20.6	20.4	19.7	20.2	19.1	19.3	18.4	18.6	18.1	15.3
$/mil gal	43.81	42.19	41.46	41.40	43.32	45.38	46.21	49.30	52.37	44.27
Total operating cost:										
$, in millions	4.074	4.272	4.579	5.030	5.830	6.285	6.934	7.593	8.431	9.262
$/mil gal	212.65	206.82	210.47	204.95	226.78	235.14	251.15	265.04	289.34	286.95

TABLE 14 (Continued). AVERAGE OPERATING AND CAPITAL COSTS FOR ALL FIVE UTILITIES OVER THE 10-YEAR STUDY PERIOD

Item	Years									
	1	2	3	4	5	6	7	8	9	10
CAPITAL COSTS:										
Depreciation ($, in millions)	1.241	1.296	1.430	1.547	1.604	1.661	1.693	1.828	1.904	2.145
Interest ($, in millions)	0.996	0.920	0.948	1.286	1.267	1.428	1.411	1.488	1.707	1.848
Total capital costs ($, in millions)	2.238	2.217	2.378	2.833	2.871	3.090	3.104	3.316	3.612	3.993
TOTAL OPERATING AND CAPITAL COSTS:										
$, in millions	6.313	6.490	6.958	7.864	8.702	9.375	10.039	10.915	12.044	13.256
$/mil gal	332.88	322.45	328.39	327.37	340.26	354.23	370.57	387.88	425.93	416.74

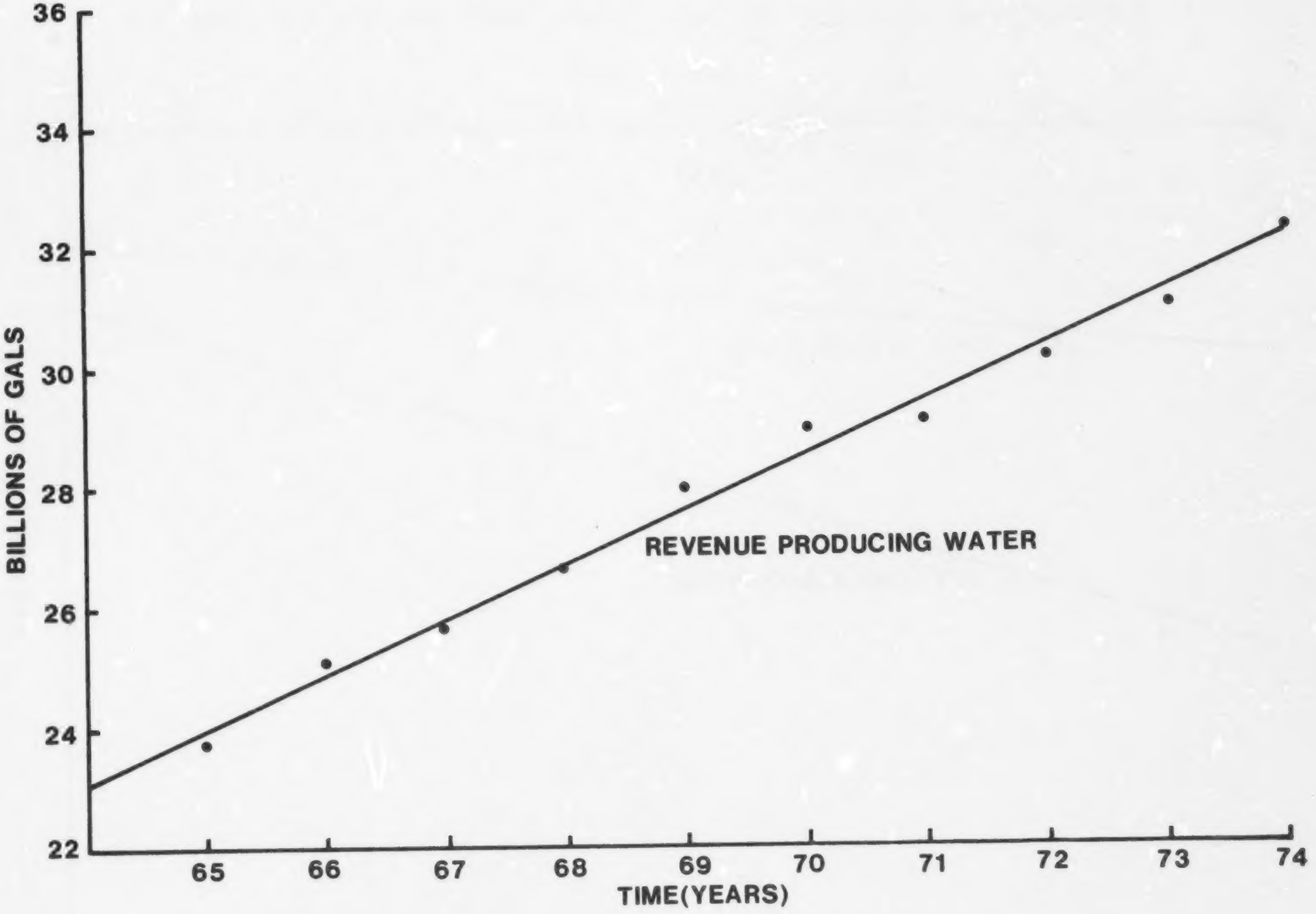

FIG. 62 AVERAGE REVENUE PRODUCING WATER

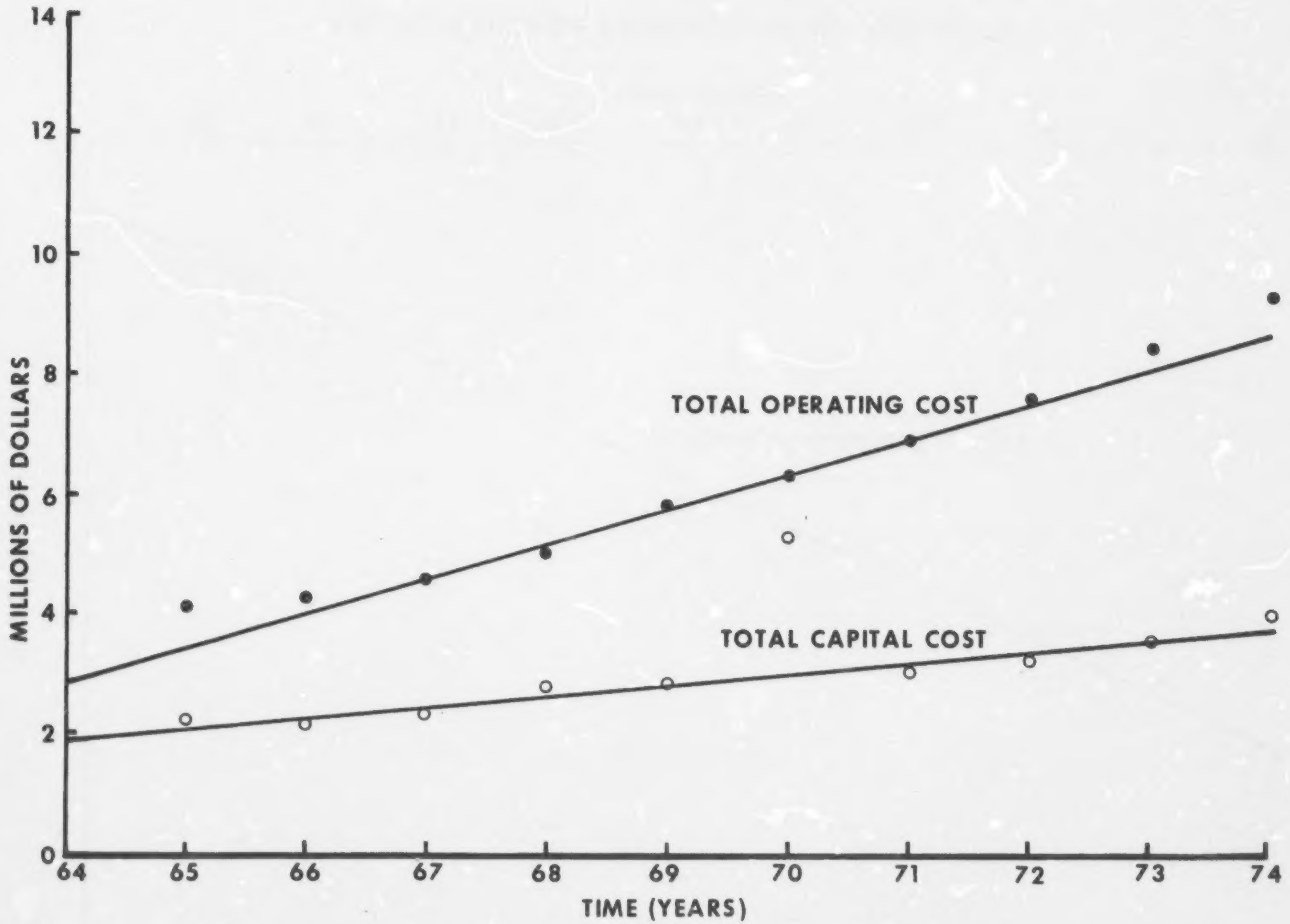

FIG. 63 AVERAGE TOTAL OPERATING AND CAPITAL EXPENDITURES

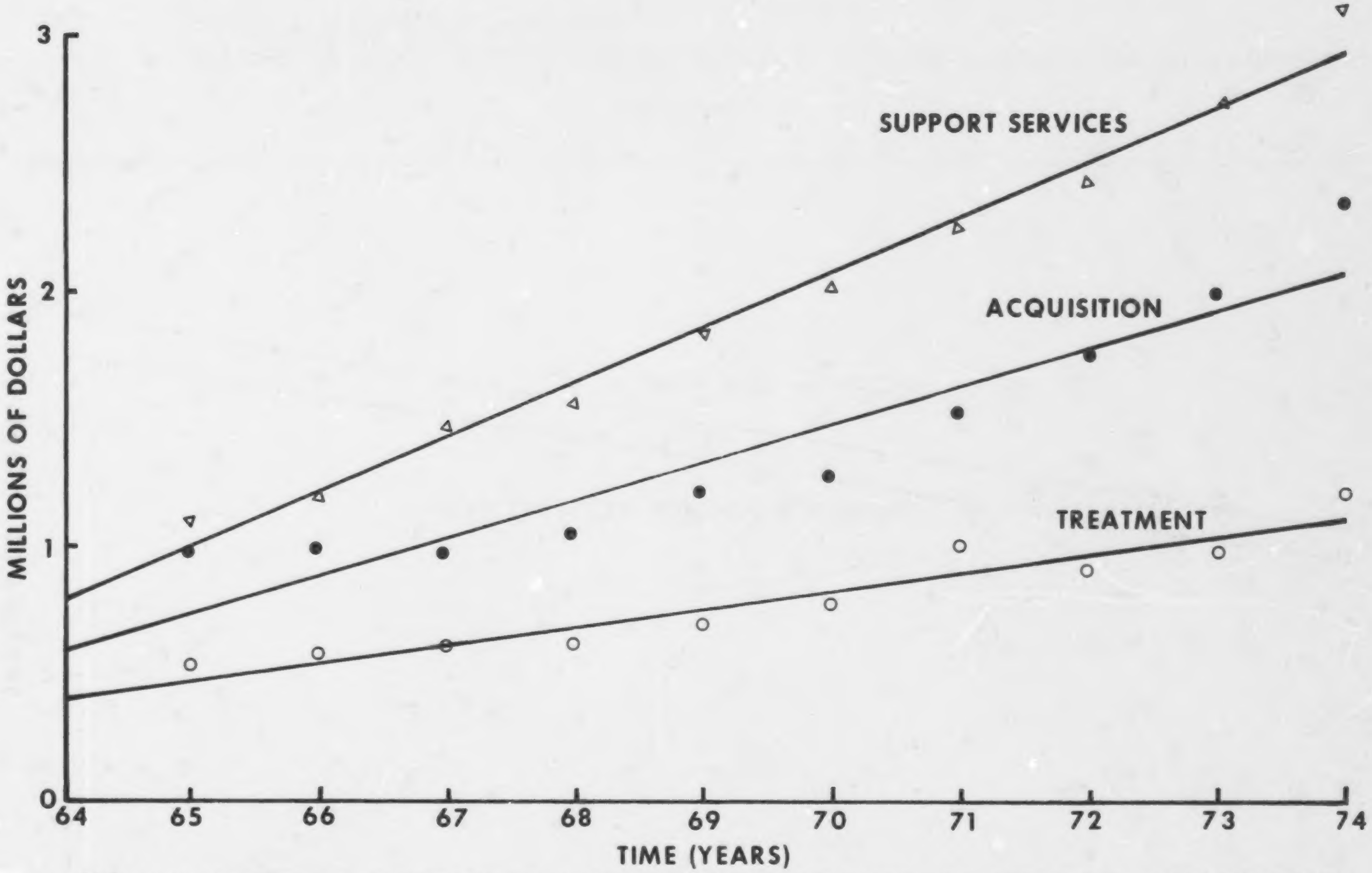

FIG. 64 AVERAGE OPERATING EXPENDITURES FOR SUPPORT SERVICES, ACQUISITION, AND TREATMENT

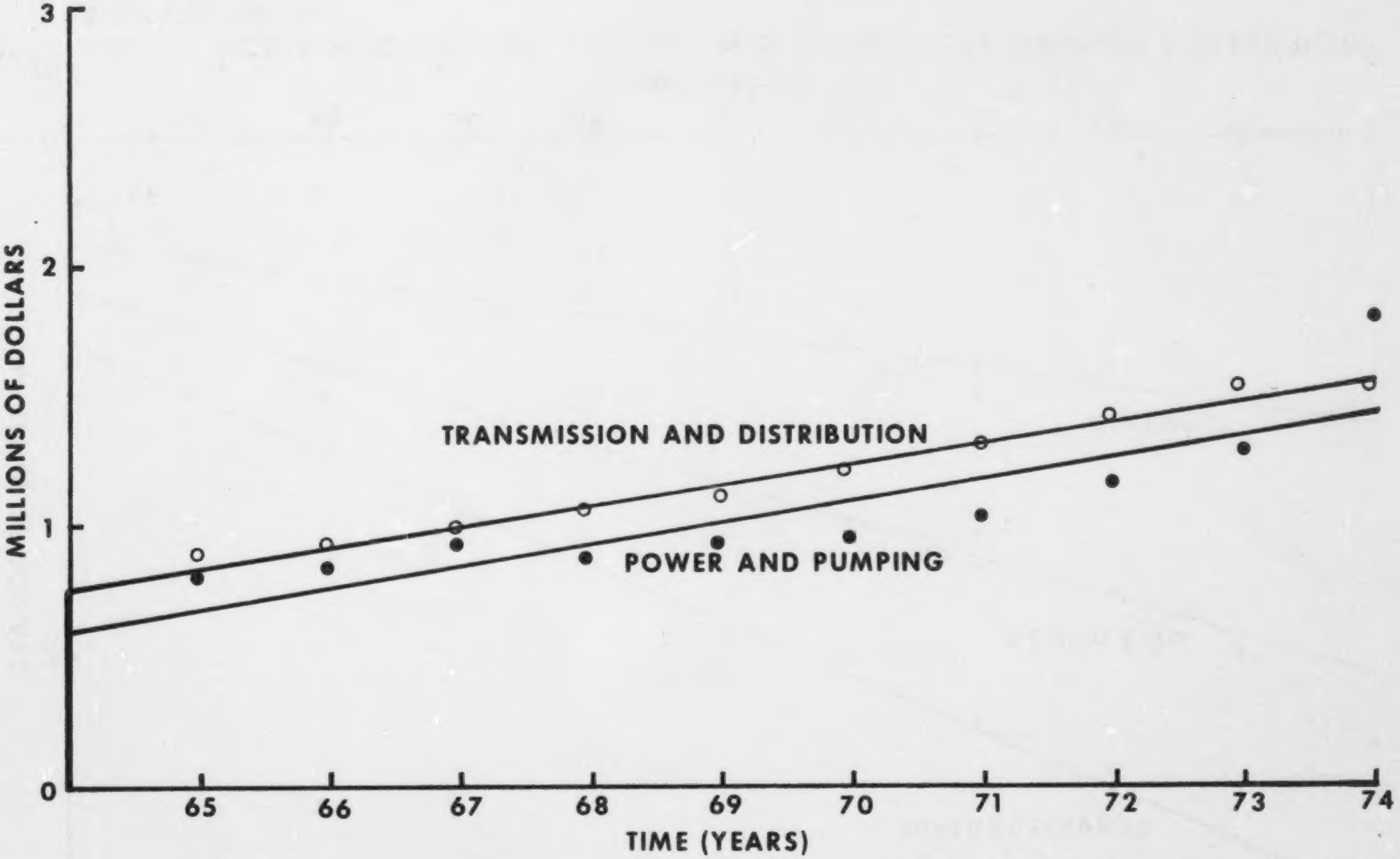

FIG. 65 AVERAGE OPERATING EXPENDITURES FOR TRANSMISSION AND DISTRIBUTION AND POWER AND PUMPING

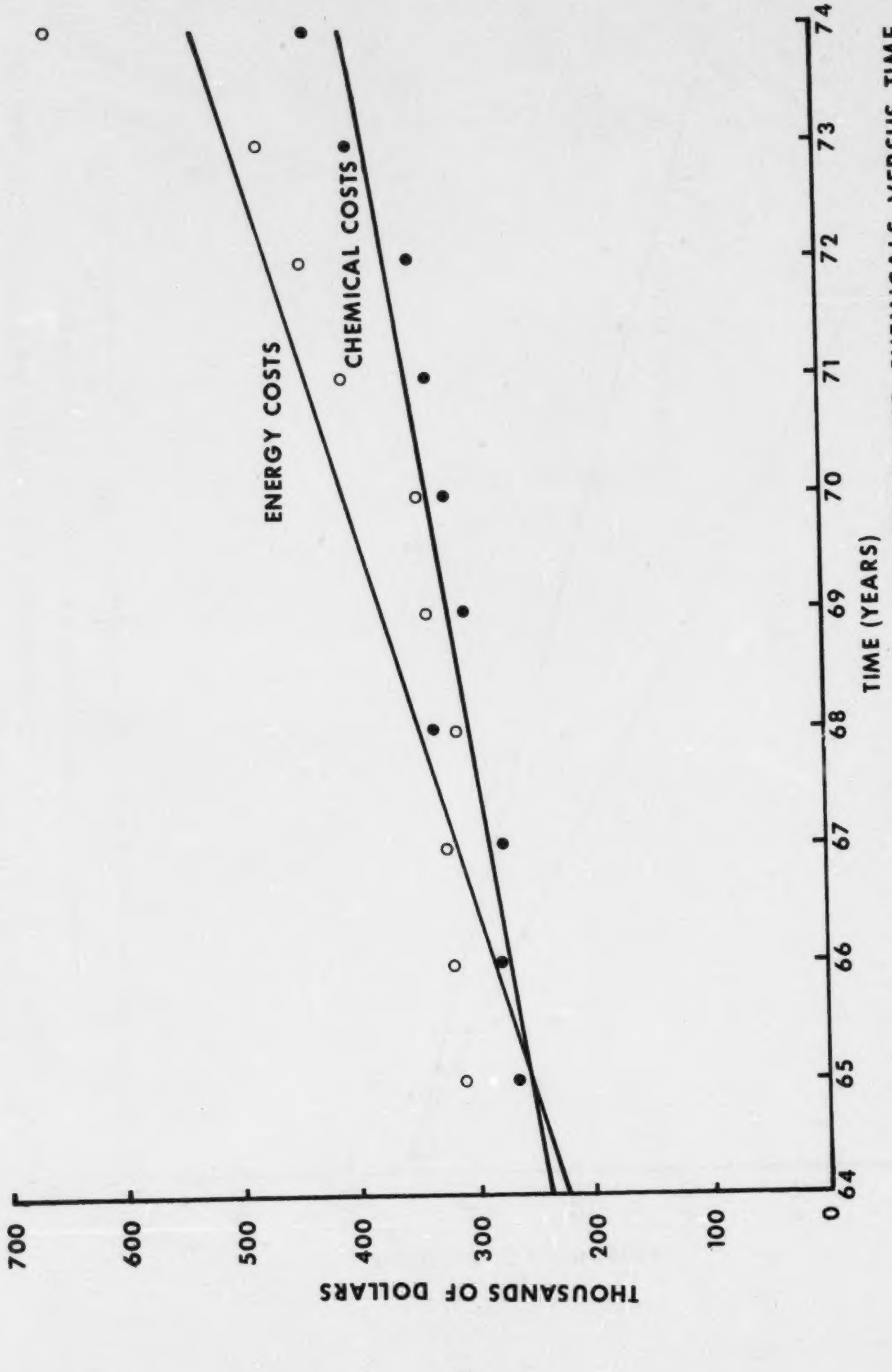

FIG. 66 AVERAGE OPERATING EXPENDITURES FOR ENERGY AND CHEMICALS VERSUS TIME

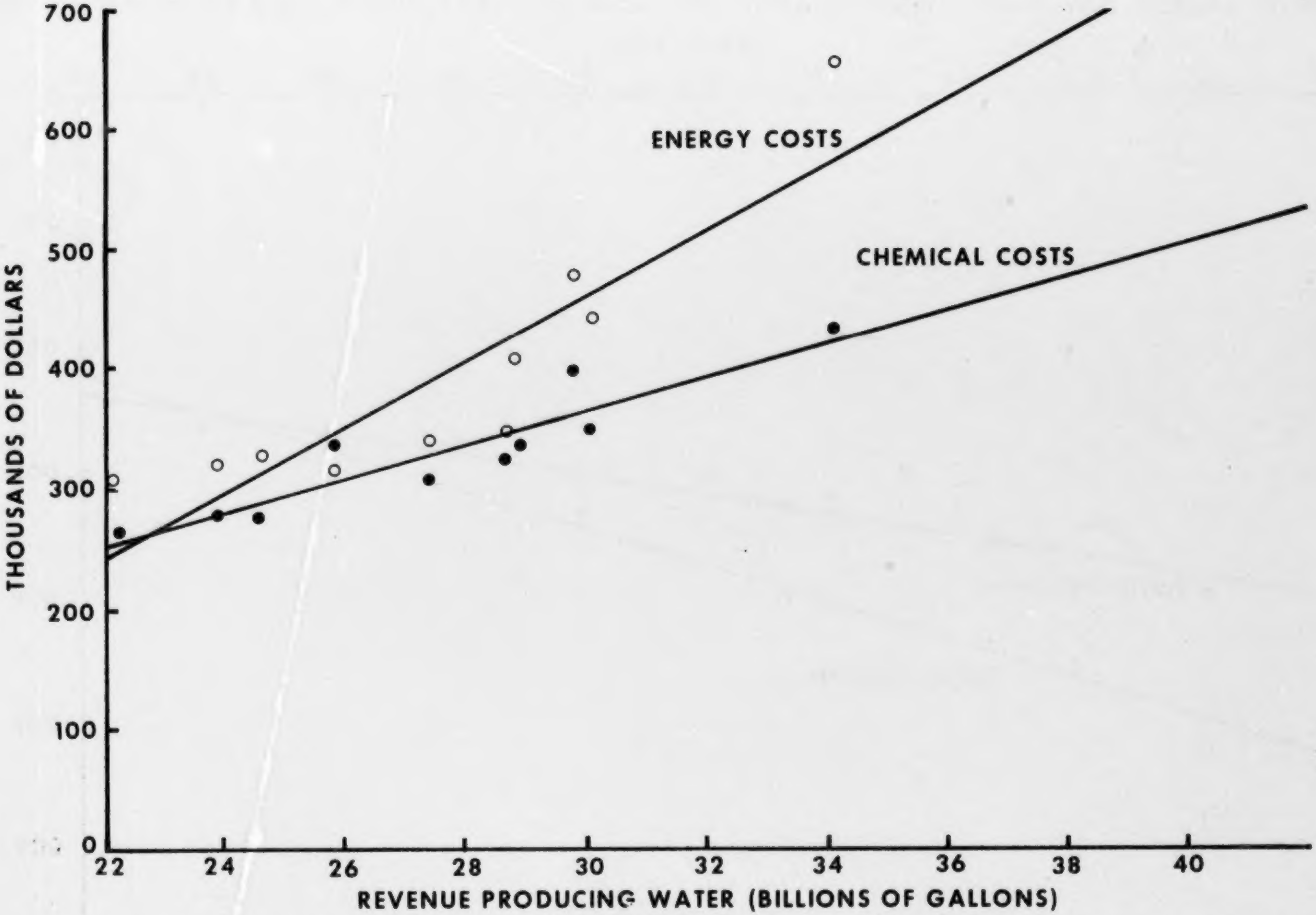

FIG. 67 AVERAGE OPERATING EXPENDITURES FOR ENERGY AND CHEMICALS VERSUS REVENUE PRODUCING WATER

TABLE 15. MANPOWER COSTS AND PRODUCTIVITY

Cost item	Year									
	1	2	3	4	5	6	7	8	9	10
Total payroll	1,713,806	1,825,217	2,006,525	2,237,453	2,525,527	2,724,751	3,040,661	3,392,529	3,665,588	3,857,361
Total hours on payroll	659,156	683,602	716,616	743,340	756,145	754,778	787,736	794,503	816,389	813,789
Metered consumption (mil gal)	22,193	23,930	24,619	25,864	27,456	28,736	28,904	30,159	29,857	34,169
Total payroll metered ($/mil gal)	77.22	76.27	81.50	86.51	91.98	94.82	105.20	112.49	122.77	112.89
Total hours metered consumption (hrs/mil gal)	33.75	32.50	30.42	29.85	31.17	29.70	30.32	29.83	30.50	28.32
Average cost per man-hour	2.60	2.67	2.80	3.01	3.34	3.61	3.86	4.27	4.49	4.74
Capital/labor cost ratio	1.31	1.21	1.18	1.27	1.14	1.13	1.02	0.98	0.99	1.04

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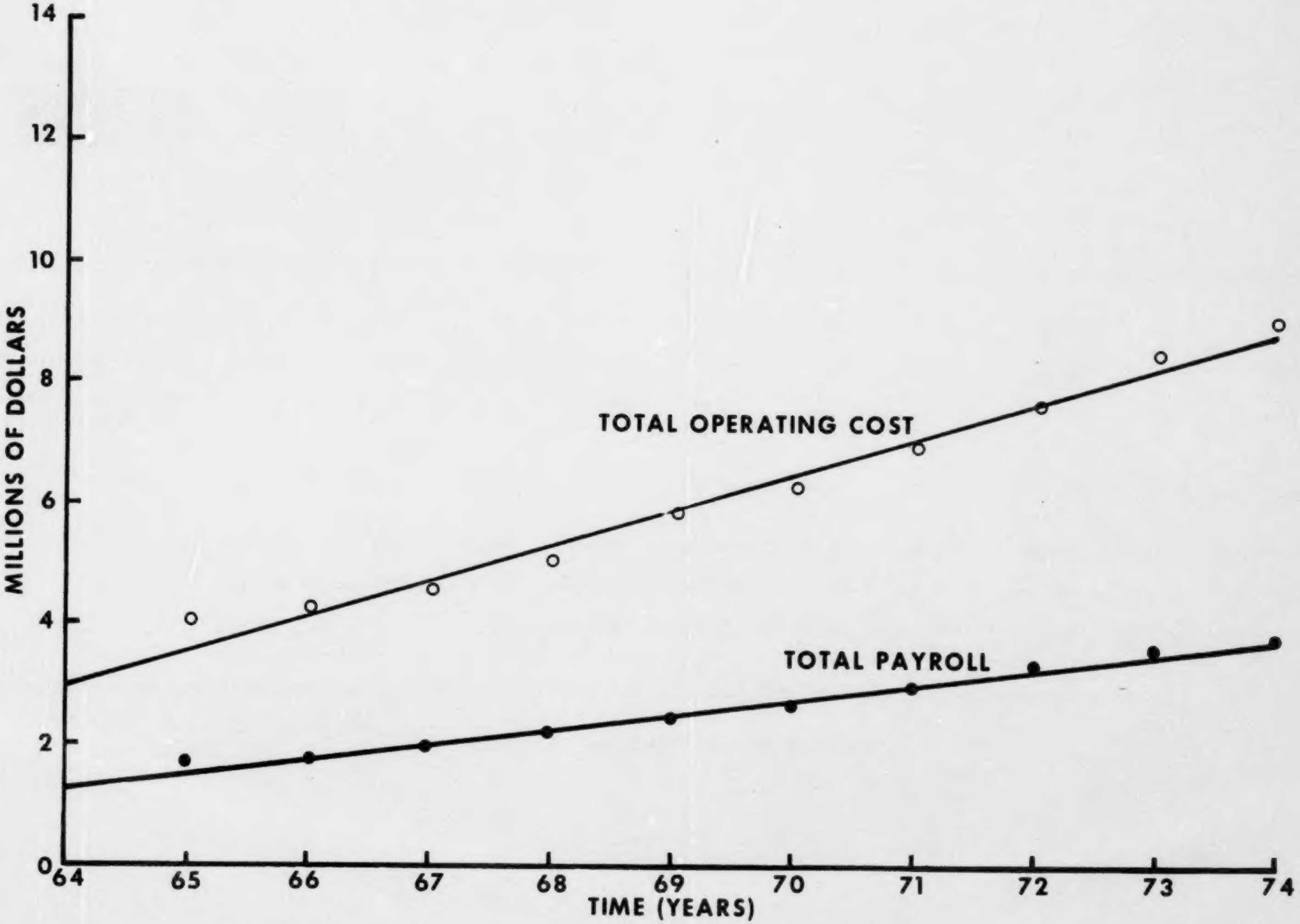

FIG. 68 AVERAGE EXPENDITURE FOR OPERATING AND PAYROLL COSTS

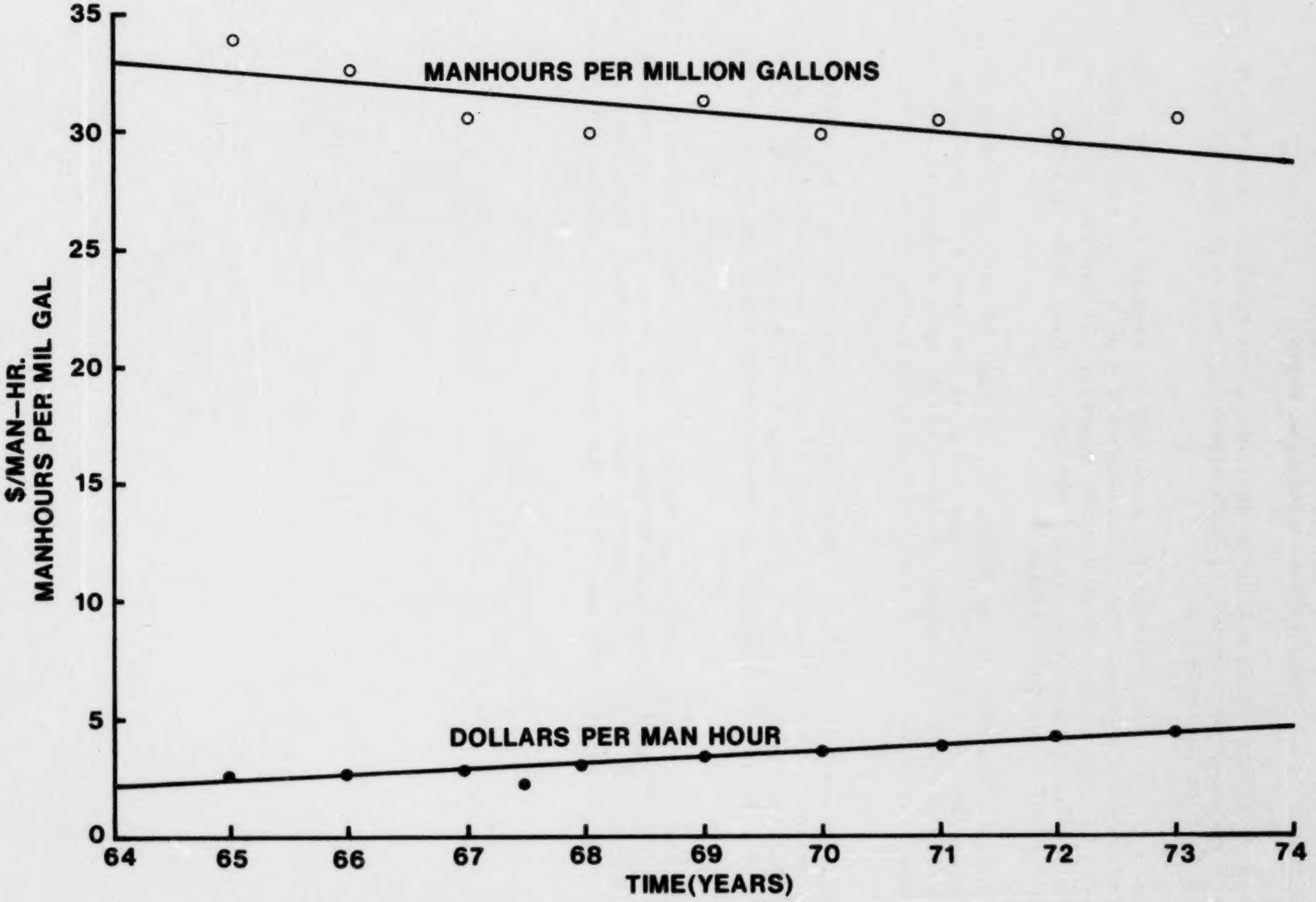

FIG. 69 MANHOURS PER MIL GAL AND DOLLARS PER MAN HOUR

productivity. Figures 70 and 71 summarize unit operating and capital costs as they relate to time and revenue-producing water.

Figures 72 and 73 show average unit costs for the five utilities versus time and revenue-producing water, both historical and corrected by the CPI, assuming 1965 as the base year.

Table 16 contains the best fit equation for some of the major items mentioned in this section. The relationship $C = aQ^b e^{st}$ is used to show dependency of cost with both production quantity (Q) and time (e^{st}). By virtue of this analysis, one can see the way in which time influences the cost of some of these cost categories.

Figures 63 through 73 and Tables 14, 15, and 16 show that water costs are affected by the same inflationary costs as the general economy, but that economies of scale and increases in productivity have managed to keep unit costs down. The unit cost of water has actually decreased when corrected by the CPI.

Figure 68 and Table 15 show that payroll costs account for approximately 42% of the total operating cost for the 12 utilities. Labor accounts for only 27% of the operating cost in San Diego so that when San Diego figures are removed, labor costs are 52% of the operating costs for the remaining 11 utilities.

Another factor not included in total payroll is fringe benefits. Using data from all 12 utilities, it is estimated that fringe benefits would add approximately 20% to the total payroll costs. Therefore, labor related costs might represent between 50% and 60% of the operating and maintenance costs.

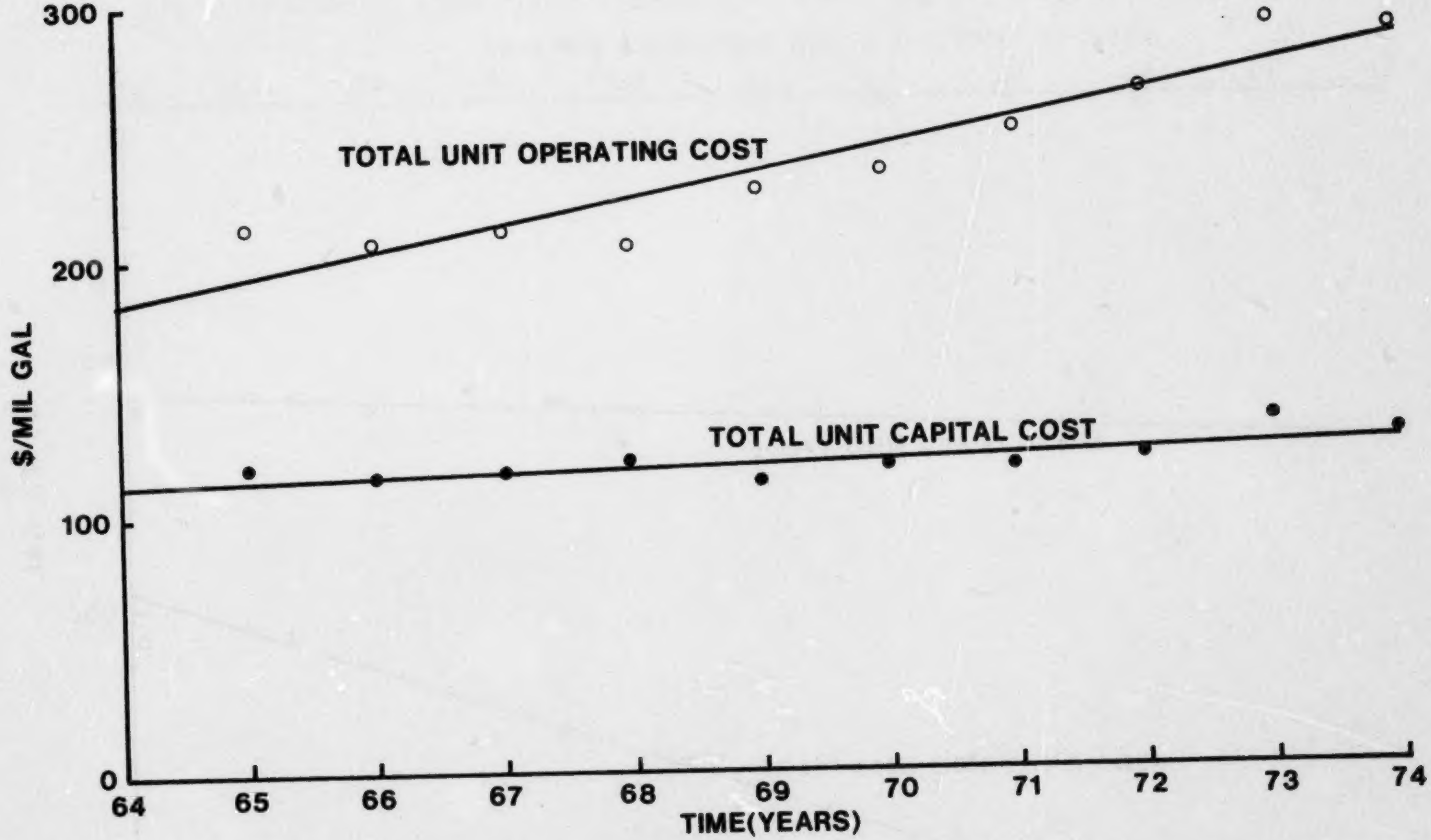

FIG. 70 AVERAGE TOTAL UNIT OPERATING AND CAPITAL COSTS VERSUS TIME

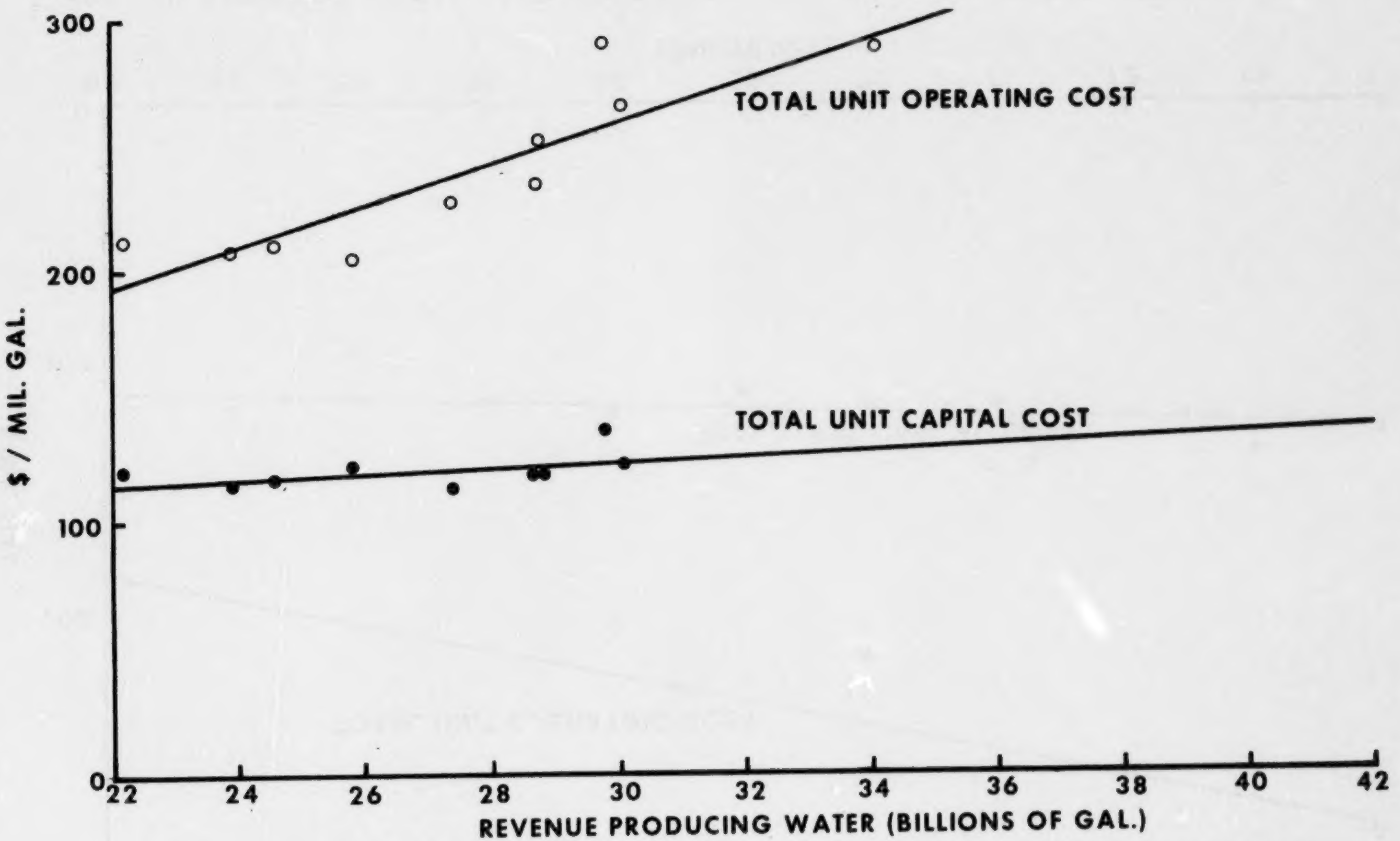

FIG. 71 AVERAGE TOTAL UNIT OPERATING, AND CAPITAL COST VERSUS REVENUE PRODUCING WATER

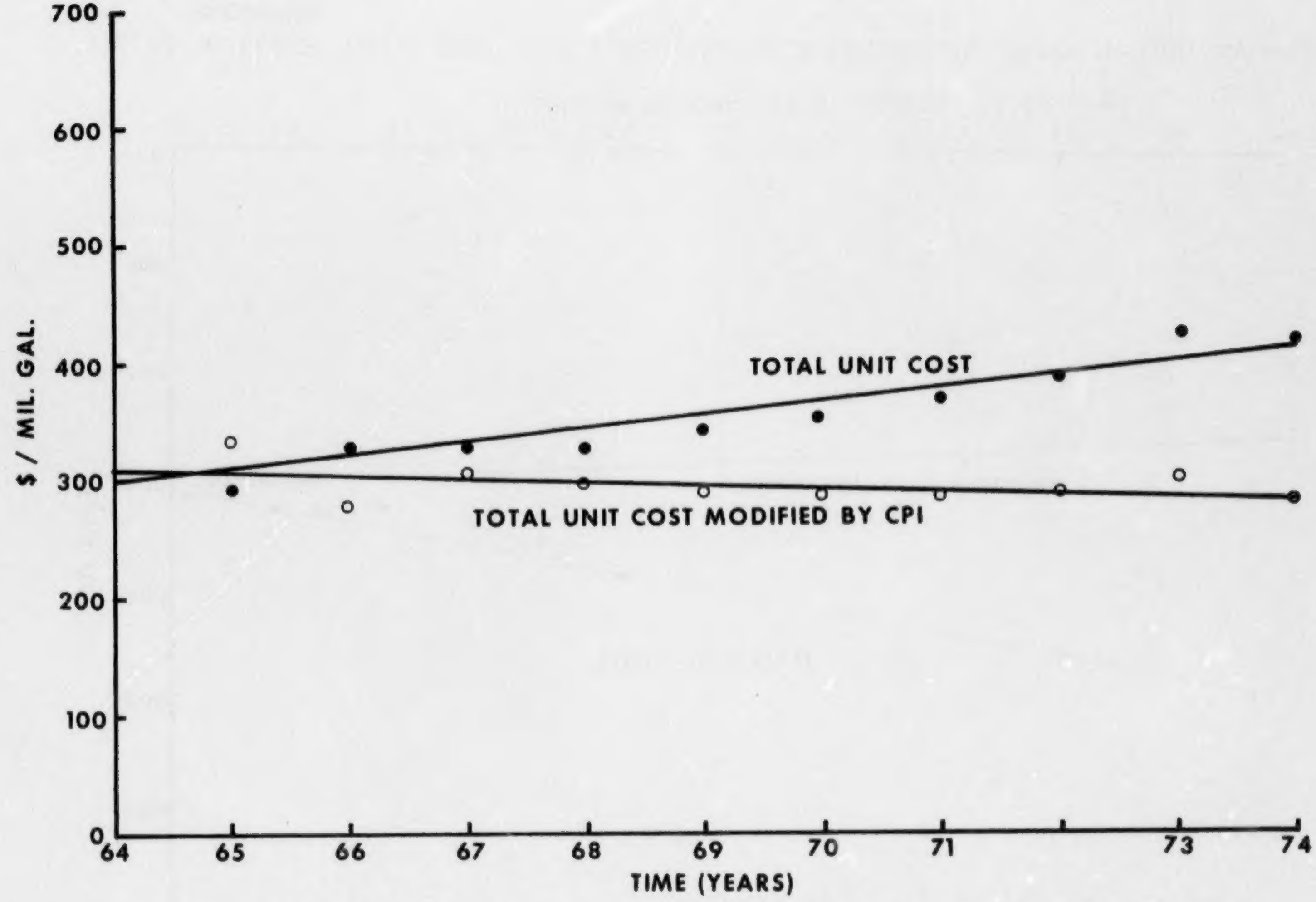

FIG. 72 AVERAGE TOTAL UNIT COST VERSUS TIME: HISTORICAL AND MODIFIED

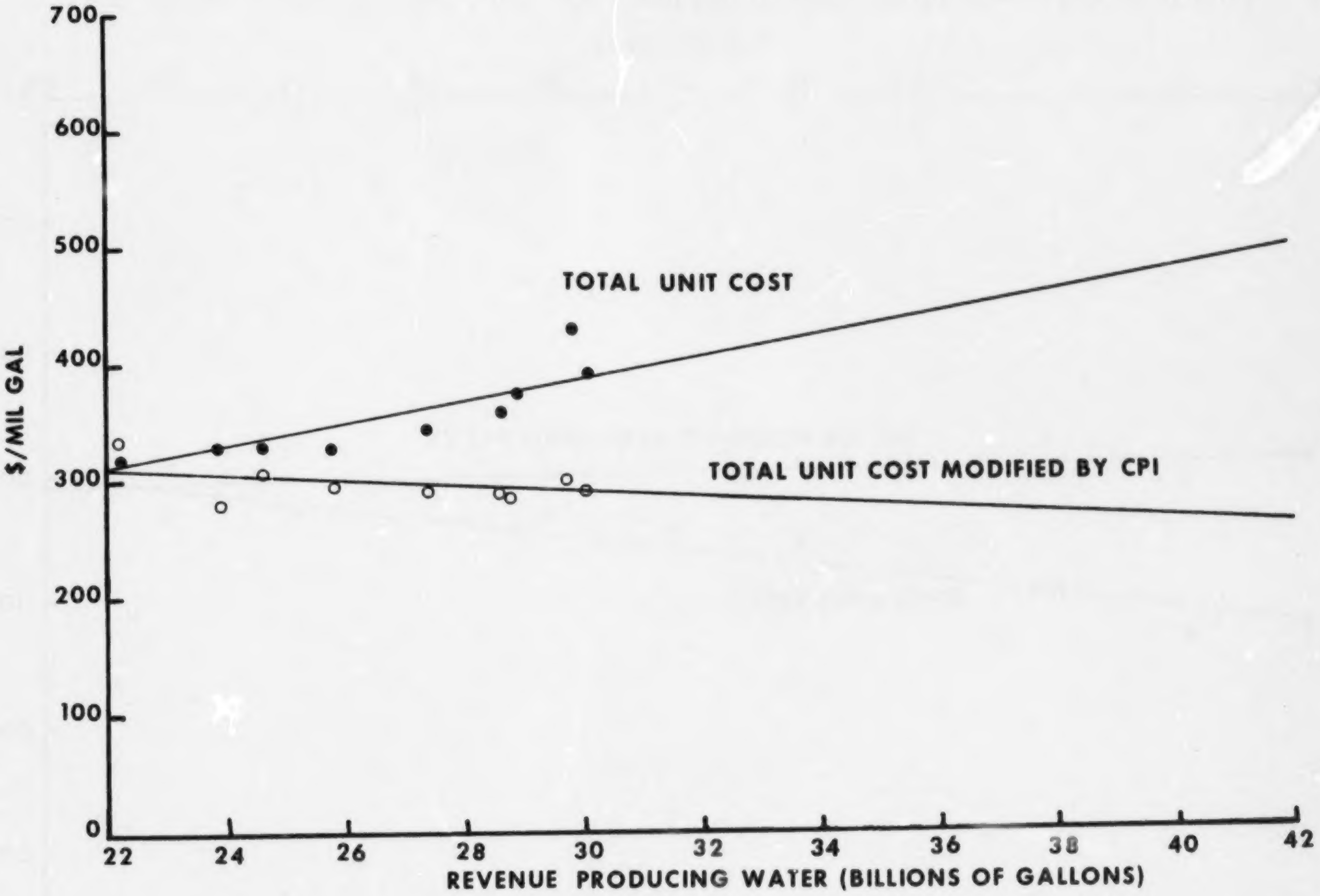

FIG. 73 AVERAGE TOTAL UNIT COST VERSUS REVENUE PRODUCING WATER: HISTORICAL AND MODIFIED

TABLE 16. O & M AND CAPITAL COSTS FOR ALL UTILITIES

Item	Operating Cost $C = aQ^b e^{st*}$				Capital Cost $C = aQ^b e^{st*}$			
	a	b	s	r^2	a	b	s	r^2
Acquisition	1.4	1.23	0.043	.64	2×10^{-8}	2.94	0.000	0.67
Treatment	2379.1	0.52	0.063	0.56	32.8	0.82	0.066	0.40
Transmission and Distribution	211.0	0.82	0.052	0.92	178.0	0.89	0.036	0.86
Support Services	78.43	0.95	0.073	.95	24.35	0.88	0.044	0.66
Total	360.4	0.91	0.056	0.93	193.8	0.91	0.043	0.86

* t is relative time, starting with year 1 as the first year of data.

Q is revenue-producing water in mil gal per year.

C is annualized cost in dollars (exclusive of interest).

SECTION 7

MODEL DEVELOPMENT

Annual Operating and Capital Costs

With data developed in the previous sections, a set of equations can be derived that relates a selected set of variables to the cost of water supply. The first relationship to be developed using regression analysis is as follows:

$$AOC = 20.13 (D_{mh})^{0.69} (M_{mg})^{0.54} Q^{0.96} (r^2 = 0.96) \quad (1)$$

where AOC = annual operating cost

D_{mh} = \$/man-hour

M_{mg} = man-hr/mil gal

Q = revenue-producing water for a given year in mil gal/year

Equation 1 demonstrates the important relationship that exists between the variables that describe labor cost (\$/man-hr), productivity (man-hr/mil gal), revenue-producing water, and annual operating cost (AOC). As can be seen from Equation 1, AOC increases nearly linearly with respect to increases in revenue-producing water if labor cost and productivity are constant. The previous section indicates that labor cost has been rising at a faster rate than productivity, but the increase in productivity (decreasing man-hr/mil gal) has tended to keep operating costs down. The partial derivatives for Equation 1 with respect to the independent variables are as follows:

$$\frac{\partial AOC}{\partial D_{mh}} = 13.89 (D_{mh})^{-0.31} (M_{mg})^{0.54} (Q)^{0.96} \quad (2)$$

$$\frac{\partial AOC}{\partial M_{mg}} = 10.87 (D_{mh})^{0.69} (M_{mg})^{-0.46} Q^{0.96} \quad (3)$$

$$\frac{\partial AOC}{\partial Q} = 19.32 (D_{mh})^{0.69} (M_{mg})^{0.54} Q^{-0.04} \quad (4)$$

Equations 2, 3, and 4 demonstrate the relative changes in cost that would take place with changes in labor cost, productivity, and revenue-producing water, assuming all other variables are constant.

Taking the natural log of Equation 1 yields:

$$\ln AOC = 3.00 + 0.69 \ln D_{mh} + 0.54 \ln M_{mg} + 0.96 \ln Q \qquad (5)$$

It is possible to study the effect of holding the rate of change for Equation 5 constant.

For example, if $\partial(\ln AOC)/\partial(\ln D_{mh}) = 0$ (6)

then $$\frac{\partial(\ln M_{mg})}{\partial(\ln D_{mh})} = -1.28 \qquad (7)$$

Therefore, if D_{mh} increases, then M_{mg} must decrease for Equation 6 to hold.

If $(M_{mg}^{(1)}, D_{mh}^{(1)})$ and $(M_{mg}^{(2)}, D_{mh}^{(2)})$ represent two sets of data points,

then $M_{mg}^{(1)}/M_{mg}^{(2)} = (D_{mh}^{(1)}/D_{mh}^{(2)})^{-1.28}$ (8)

If $M^{(1)}_{mg}$ = 28 man-hours/mil gal and $D_{mh}^{(1)}$ = \$4.8/hour and if $D_{mh}^{(2)}$

= \$9.6/hour, then the following relationship must hold:

$$M_{mg}^{(2)} = (M_{mg}^{(1)}) \frac{((D_{mh}^{(1)})}{(D_{mh}^{(2)})} \qquad (9)$$

$$M_{mg}^{(2)} = 11.5 \frac{\text{man-hours}}{\text{mil gal}}$$

As shown by Equation 9, the productivity must more than double for the cost to stay constant. Similar relationships can be derived for the other variables using partial derivatives. These partials are summarized in Table 17.

TABLE 17. PARTIAL DERIVATIVES FOR EQUATION 5

x = y =	$\partial x/\partial y$		
	$\ln D_{mh}$	$\ln M_{mg}$	$\ln Q$
$\ln D_{mh}$	---	- 1.28	- 0.72
$\ln M_{mg}$	- 0.78	---	- 0.56
$\ln Q$	- 1.39	- 1.78	---

The Annual Capital Cost is given by the following relationship:

$$ACC = 25.7\,(D/Q)^{0.74}\,Q^{0.84} \qquad (r^2 = 0.92) \qquad (10)$$

where ACC = Annual capital cost

D = Annual depreciation

Q = Annual revenue-producing water

If, in Equation 10, D/Q = U, then the natural log transform is as follows:

$$\ln ACC = 3.25 + 0.74 \ln U + 0.84 \ln Q \qquad (11)$$

The partials for Equation 11 are shown in Table 18.

TABLE 18. PARTIAL DERIVATIVES FOR EQUATION 10

x =	∂x/∂y	
y =	ln U	ln Q
ln U	---	- 0.88
ln Q	= 1.14	---

If one wished to know the relationship between the unit depreciation and Q, one could formulate the following relationship:

$$U^{(2)} = U^{(1)} \quad (Q^{(1)}/Q^{(2)})^{1.14} \tag{12}$$

If $Q^{(1)}$ and $U^{(1)}$ are 4 x 10^6 mil gal and \$117.65/mil gal, respectively, then if Q^2 increases to 4.5 x 10^6, $U^{(2)}$ = 103.01 for ACC to remain constant. Obviously, if U^2 increases, then ACC will increase.

For the water utilities studied, another relationship can be formulated that relates interest to depreciation. It is as follows:

$$I = 104.6 \ D^{0.65} \tag{13}$$

Equations 1 and 10 can be combined to yield an annual total cost equation, as shown below:

$$ATC = 20.13 \ D_{mh}^{\ 0.69} \ M_{mg}^{\ 0.54} \ Q^{0.96} + 25.7 \ (D/Q)^{0.74} \ Q^{0.84} \tag{14}$$

It can be seen from Equations 1, 5, and 14 that if capacity is increased, the value for D/Q will increase accordingly, and ACC will rise at a more rapid rate than AOC. Therefore, when capacity is increased sharply the ratio of AOC to ACC will drop for a period of time and then increase gradually.

Equations 1, 10, and 14 give annual operating, capital, and total costs for the utilities studied and Table 19 provides a mechanism for assigning cost by individual cost category. For example, line 1 of Table 19 shows that 31% of the operating costs are associated with support services. Assuming that this percentage stays constant with changes in the independent variables, it can be used to estimate the proportion of annual cost that can be assigned to support services. Line 2 of Table 19 contains the percentages by cost category for capital costs.

TABLE 19. UTILITY COSTS BY CATEGORY

	Percent of Cost by Category				
Item	Support Services	Acquisition	Treatment	Power & Pumping	Transmission & Distribution
Operating Cost	31	22	8	16	19
Capital Cost	9.8	12.6	10.3	-	67.3

Production Related Costs

Another important cost relationship is between annual operating and capital costs and revenue-producing water. Table 20 summarizes these costs for acquisition, treatment, transmission and distribution, and support services, using the equation form

$$y = AQ^b \qquad (15)$$

The operating cost data are the annual operating expenditures for a given cost category corrected to 1974, using the CPI. Capital costs are given as annual depreciation, also corrected to 1974. For example, it can be seen that both annual capital and operating costs for the utilities studied are increasing at an increasing rate for acquisition. This result implies that as the amount of revenue-producing water increases the utility must seek sources farther and farther away from the treatment plant, resulting in costs increasing at an increasing rate with Q. The results in Table 20 for treatment capital costs are somewhat different than might be expected from intuition. It is normally assumed that economies of scale exist with respect to treatment capacity ($b < 1$).

TABLE 20. RELATIONSHIP BETWEEN ANNUAL COST AND REVENUE-PRODUCING WATER*
(Corrected to 1974)

	Operating Cost** $C = aQ^b$			Capital Cost** $C = aQ^b$		
Item	a	b	r^2	a	b	r^2
Support services	141	0.95	0.94	3.61	1.06	0.76
Acquisition	2.1	1.23	0.64	2.4×10^{-8}	2.89	0.67
Treatment	4202	0.53	0.53	5.2	1.01	0.52
Transmission and Distribution	358	0.82	0.91	25.7	1.06	0.89
Total	621	0.91	0.93	28.7	1.09	0.89

* Power and pumping costs have been allocated into other cost categories.

** C = annual cost in dollars, a = constant, b = rate of change, Q = revenue-producing water in mil gal/yr.

The results reported in Table 20 are the annualized cost of capital (exclusive of interest) corrected to 1974, using the CPI. These costs include the effects of inflation over time. In Table 16 these effects are accounted for by the term e^{st}. Results from Table 20 confirm by their linearity that the unit cost of water has remained fairly constant when inflation has been removed. Two other factors influence the unexpected value for b. One is that the independent variable is revenue-producing water which is always less than design capacity. The second is that these costs include capital improvements and system add-on which may be more nearly linear in cost as compared to initial investments. As demand increased, it is often met by the addition of a relatively small facility, building block fashion. Adding increments of capacity in this manner over time no doubt eliminates some economies of scale in initial construction.

Equation 16 is a relationship between total chemical costs, and revenue-producing water and source quality:[12]

$$C_c = 25.50\ Q^{0.91}\ (1.91)^X \qquad (r^2 = 0.71) \tag{16}$$

where C_c = Annual chemical costs corrected to 1974 dollars

Q = Revenue-producing water

X = 1 for poor quality surface source water; 0 for high quality ground or protected surface source water.

if X = 1, then

$$C_c = 48.6\ Q^{0.91} \tag{17}$$

if X = 0, then

$$C_c = 25.5\ Q^{0.91} \tag{18}$$

Equation 19 shows the relationship between annual power cost and revenue-producing water and head:

$$C_p = 154.3\ Q^{0.77}\ (1.34)^{X_1}\ (1.23)^{X_2} \qquad (r^2 = 0.90) \tag{19}$$

where C_p = Annual power cost in 1974 dollars

Q = Revenue-producing water

X_1 and X_2 = Dummy variables such that: $X_1 = 1$, $X_2 = 1$ are the conditions for high head pumping above 700 ft.; $X_1 = 1$, $X_2 = 0$ are conditions for medium elevation pumping 300 - 700 ft; $X_1 = 0$, $X_2 = 0$ are the conditions for low head pumping 0 - 300 ft.

For example, if $X_1 = 1$, $X_2 = 1$ then

$$C_p = 349.2\ Q^{0.78} \tag{20}$$

if $X_1 = 1$, $X_2 = 0$ then

$$C_p = 283.9\ Q^{0.78} \tag{21}$$

and if $X_1 = 0,\ X_2 = 0$ then

$$C_p = 154.3\ Q^{0.78} \qquad (22)$$

Cincinnati, Ohio, might provide an example of how the equation might be used. Cincinnati draws water from the Ohio River which is a poor quality surface source and water is pumped to high elevations. Therefore equations 17 and 20 would be used to estimate chemical and power costs.

Costs as a function of spatial and demographic variables -- A relationship that might be useful to many water works managers is one between unit cost and selected physical and/or demographic variables. Column 2 of Table 21 contains the incremental costs for the Cincinnati cost zones shown in Figure 24. Treatment, acquisition interest, and support services costs have been removed. Column 3 is the straight line distance from the treatment plant to the centroid of each zone, Column 4 contains the elevation at the centroid relative to the treatment plant, and Column 5 is the population density in each zone. Eq 23 expresses the relationship between unit incremental cost, population density, and distance. The equation is as follows:

$$C_u = 122.0\ P_d^{-0.65}\ D_i^{0.20} \qquad (r^2 = 0.76) \qquad (23)$$

where C_u = Unit incremental cost in \$/mil gal

P_d = Population density in thousand people/sq mi

D_i = Distance to the cost zone centroid in mi

If P_d were constant at $\overline{P}_d$, then the rate of change of incremental cost is given as shown below:

$$\frac{\partial C_u}{\partial D_1} = K_1\ D_i^{-0.80} \qquad (24)$$

where $K_1 = 24.4\ \overline{P}_d^{-0.65}$

As can be seen from Eq 24, unit cost increases at a decreasing rate with distance, assuming constant population density. If distance were held constant at $\overline{D}_i$, then the rate of change of cost with respect to P_d is as follows:

$$\frac{\partial C_u}{\partial P_d} = K_2\ P_d^{-1.65} \qquad (25)$$

where $K_2 = -79.3\ (\overline{D}_i)^{0.20}$

TABLE 21. INCREMENTAL COSTS AND ASSOCIATED STATISTICS FOR CINCINNATI WATER WORKS SERVICE AREA

Zone	Incremental Cost ($/mil gal)*	Distance to Zone Centroid (mi)**	Elevation of Centroid (ft)+	Population Density (thou people/sq mi)**
A	198.44	0.5	0.0	.384
B1	130.80	3.7	221.7	1.324
B2	271.54	6.2	325.8	.839
C1a	56.98	9.7	174.9	2.656
C1b	238.83	17.3	338.9	.674
C2	66.74	12.7	140.2	4.697
C3a	69.48	9.6	168.5	6.730
C3b	140.36	16.5	339.1	1.896
C4a	58.50	10.3	11.5	5.358
C4b	173.54	13.9	310.7	2.736

* 1 $/mil gal = 0.26×10^{-9} $/m^3

** 1 mile = 1610.4 meters

+ 1 ft = 0.91 meters

++ 1 person/sq mi = 3.874×10^{-7} thou people/m^2

As can be seen from Eq 25, the unit cost decreases at a decreasing rate with increasing population density. Taking the natural log transform of Eq 22 and differentiating and setting each partial differential equal to zero yields that data in Table 22.

TABLE 22. PARTIALS FOR NATURAL LOG TRANSFORM OF EQUATION (22)

	$\partial y/\partial y$	
x = y =	$\ln P_d$	$\ln D_i$
$\ln P_d$	-	0.31
$\ln D_i$	3.25	-

From Table 22 we see that for the cost to stay constant ($\frac{\partial C_u}{\partial D_i} = \frac{\partial C_u}{\partial P_d} = 0$) the following relationship must hold:

$$\frac{D_i^1}{D_i^2} = \left(\frac{P_d^1}{P_d^2}\right)^{0.31} \qquad (26)$$

If D_i^2 is farther away from the treatment plant than D_i^1, then population density must increase in accordance with Eq 26 for $\frac{\partial C_u^i}{\partial D_i}$ to remain constant. Generally, population density decreases with distance from the treatment plant leading to increases in unit cost due to decreasing density and increasing distance.

Another relationship that can be developed from the data in Table 21 is shown below:

$$E = 1.8\, D_i^{1.4} \quad (r^2 = 0.60) \qquad (27)$$

where E = Elevation of the cost zone in feet above the treatment plant and D_i = Radial distance to the centroid of a cost zone in mi from treatment plant.

The general topography of the Cincinnati service area verifies the accuracy of Eq 26

Eq 26 demonstrates that the incremental cost of transporting increases with distance. Assume the following:

$$C_t = \text{total cost for transporting water} \tag{28}$$

$$P_d = K \text{ (a constant)} \tag{29}$$

$$Q = \alpha D_i \text{ (water transmitted increases with distance)} \tag{30}$$

$$C_u = \frac{C_t}{Q} \tag{31}$$

or

$$C_u = \frac{C_t}{\alpha D_i} \tag{32}$$

Substituting eq 29 and 32 into eq 23 and collecting terms yield

$$C_t = 122\alpha K\ D_i^{1.20} \tag{33}$$

Since $122\alpha K$ is constant, then C_t increases with D_i.

It can also been seen from Eq 26 that, for the Cincinnati utility, unit cost increases with distance from the treatment plant and decreases with population density. Neither of the conclusions is surprising, but Eq 22 quantifies this relationship. Eq 27 shows that, for the Cincinnati utility, elevation tends to increase fairly regularly with distance from the treatment plant. Eq 23 through 33 lead to the conclusion that there may be definite limitations of the economically efficient size of a utility service area. Recognized economies of scale are offset by diseconomies of scale due to the distance water must be transported. The equations developed herein may be useful to define the most efficient system size. Once costs exceed a given value, managers and planners should consider establishing a new treatment plant if an adequate source is available. These kinds of relationships might also prove useful to the manager when making pricing decisions.

SECTION 8

COST OF IMPLEMENTING THE SAFE DRINKING WATER ACT

The previous analysis shows that water supply costs are increasing (see Figures 62 through 73). Some of these increases are due to pressure from increased consumption, and others are the results of inflationary effects. Equation 1 establishes a relationship between \$/man-hour (D_{mh}), man-hours/mil gal (M_{mg}), and production of revenue-producing water (Q). Costs for D_{mh} are heavily dependent on inflation, while costs resulting from increases in Q are more nearly related to increases in demand. Productivity in man-hours/mil gal is dependent to a large degree on management policy.

By studying the trends in water supply costs, it is possible to understand some of the economic impacts of the Safe Drinking Water Act. In the following section, historic trends will be utilized to estimate expected increases in cost. Hypothetical requirements for the proposed organic regulations in the Safe Drinking Water Act will be superimposed on these expected increases. It will be possible to separate the expected cost increases from those associated with the Safe Drinking Water Act.

TRENDS IN WATER SUPPLY

The trends established in the previous sections for a 10-year time period will be assumed in this analysis. For example, Figure 74 shows the average revenue-producing water pumped for all 12 utilities for a 10-year period ending 1974. This trend has been extrapolated through 1985. Revenue-producing water in 1974 was 32.8 billion gallons and, according to the extrapolation, will be 45.0 billion gallons in 1985 -- a 30% increase. This means an increase from a 93 mil gal/day system to a 121 mil gal/day system. Figures 75 through 78 show trends in operating and capital costs for the functional cost areas discussed earlier.

Table 23 summarizes average 1974 costs and projected average 1984 costs for all 12 utilities. The changes shown are expected changes, based on demand and inflationary pressures. Incremental costs above these expected costs resulting from the Safe Drinking Water Act will be analyzed in the following section.

IMPACT OF THE SAFE DRINKING WATER ACT

Calculations are based on the assumption that Safe Drinking Water Act control technologies will be installed by 1980. Three types of technology will be considered: granular activated carbon (GAC) with contactors, GAC

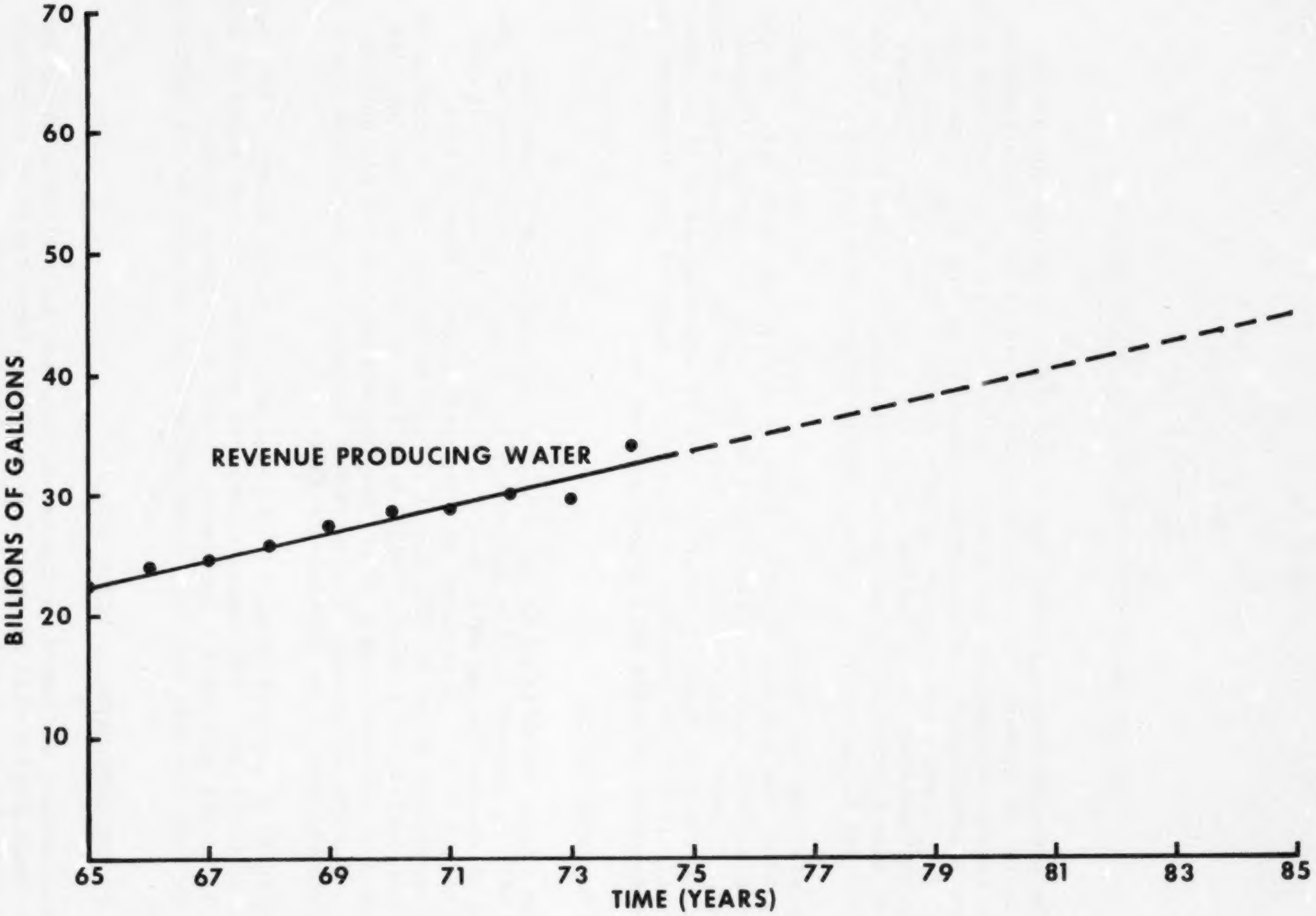

FIG. 74 REVENUE PRODUCING WATER EXTRAPOLATED OVER TIME

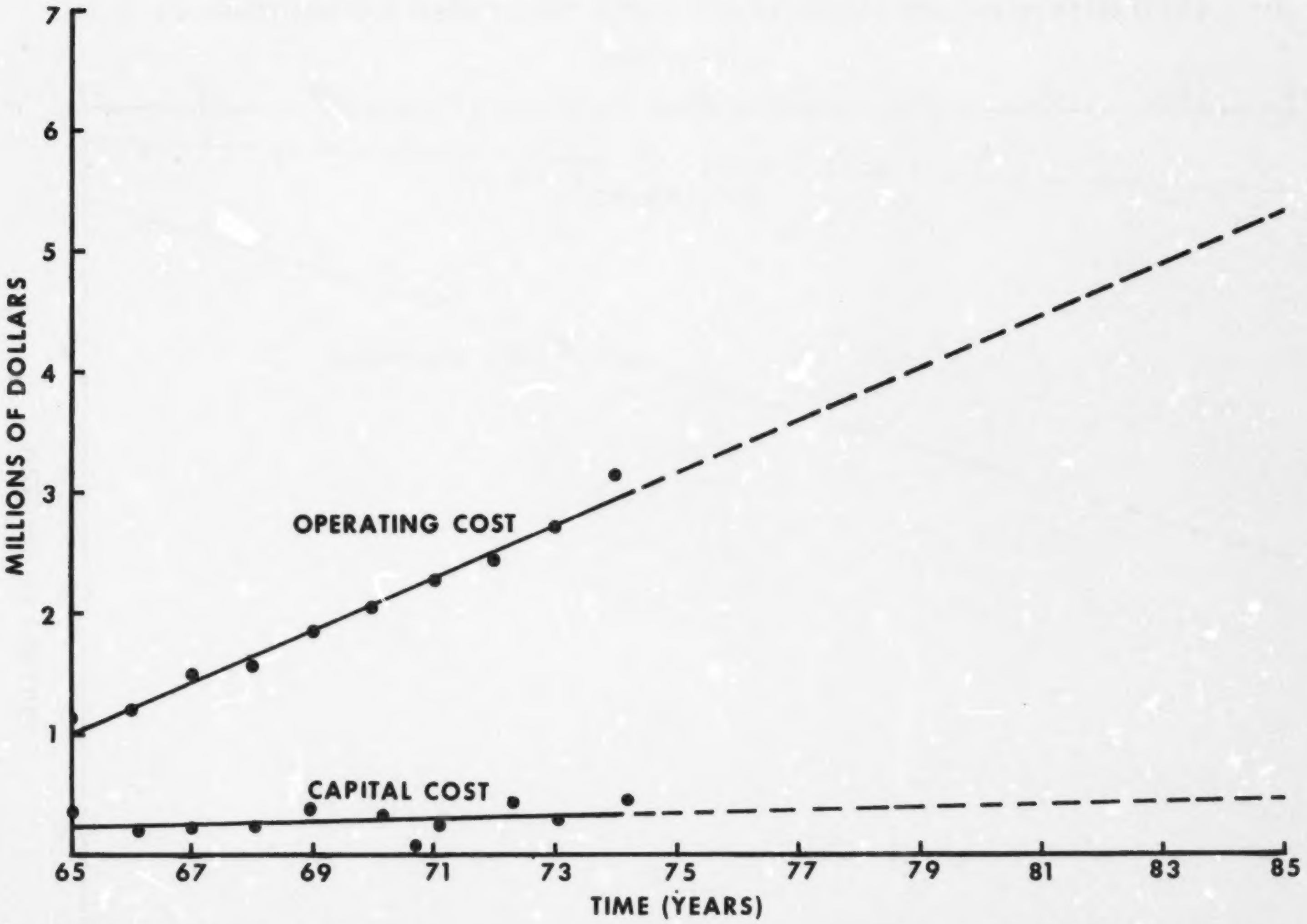

FIG. 75 SUPPORT SERVICES OPERATING AND CAPITAL COSTS EXTRAPOLATED OVER TIME

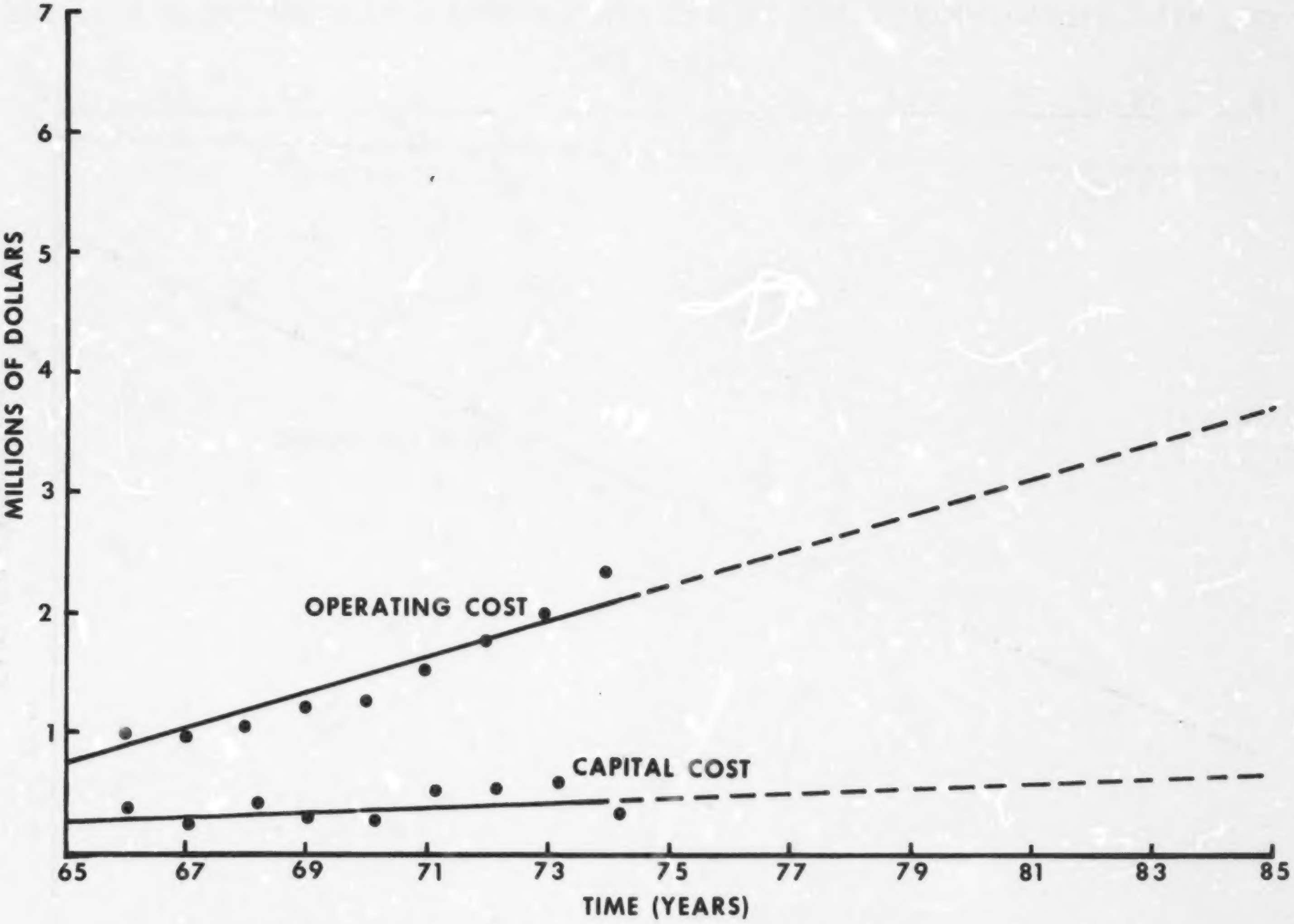

FIG. 76 ACQUISITION OPERATING AND CAPITAL COSTS EXTRAPOLATED OVER TIME

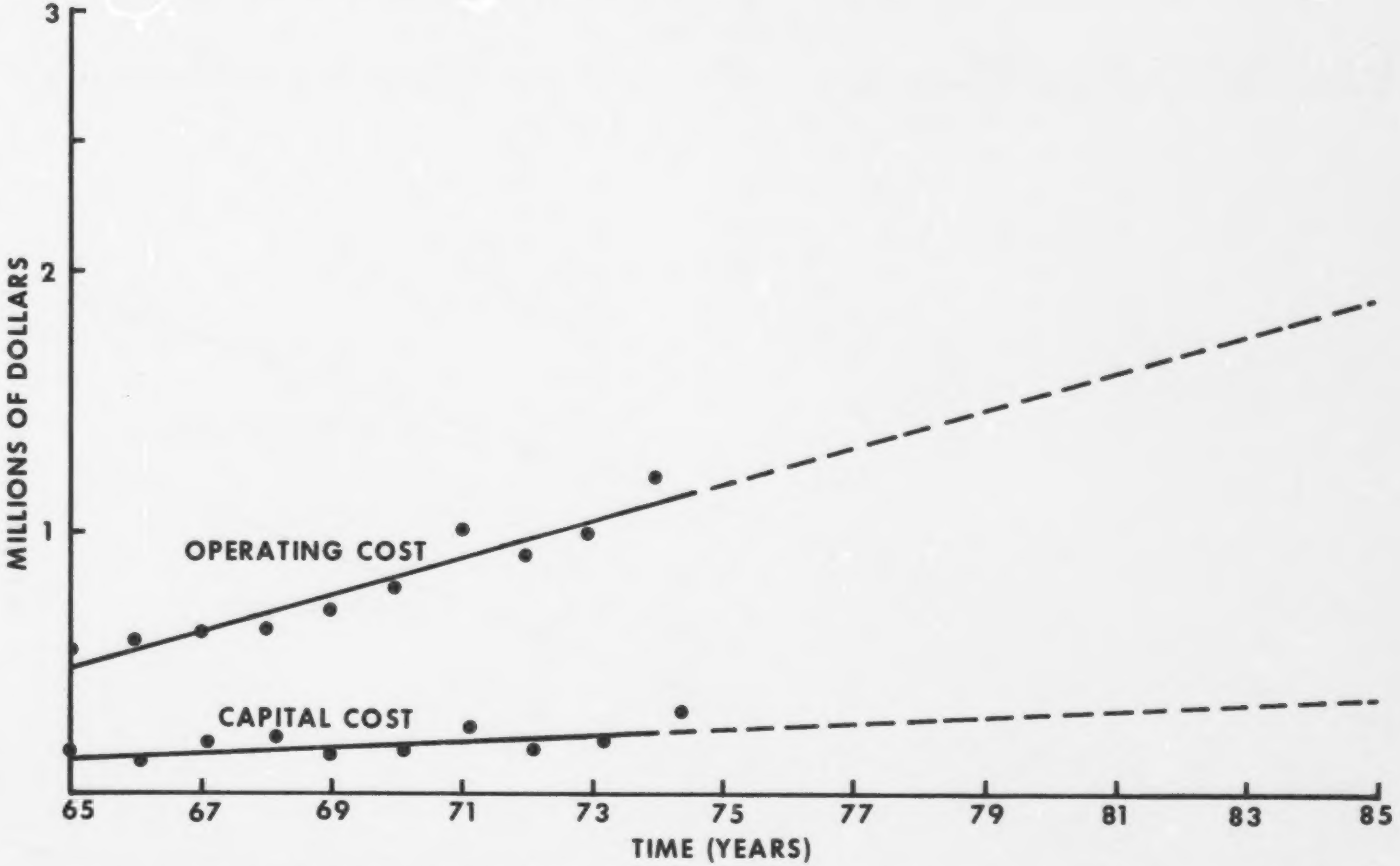

FIG. 77 TREATMENT OPERATING AND CAPITAL COSTS EXTRAPOLATED OVER TIME

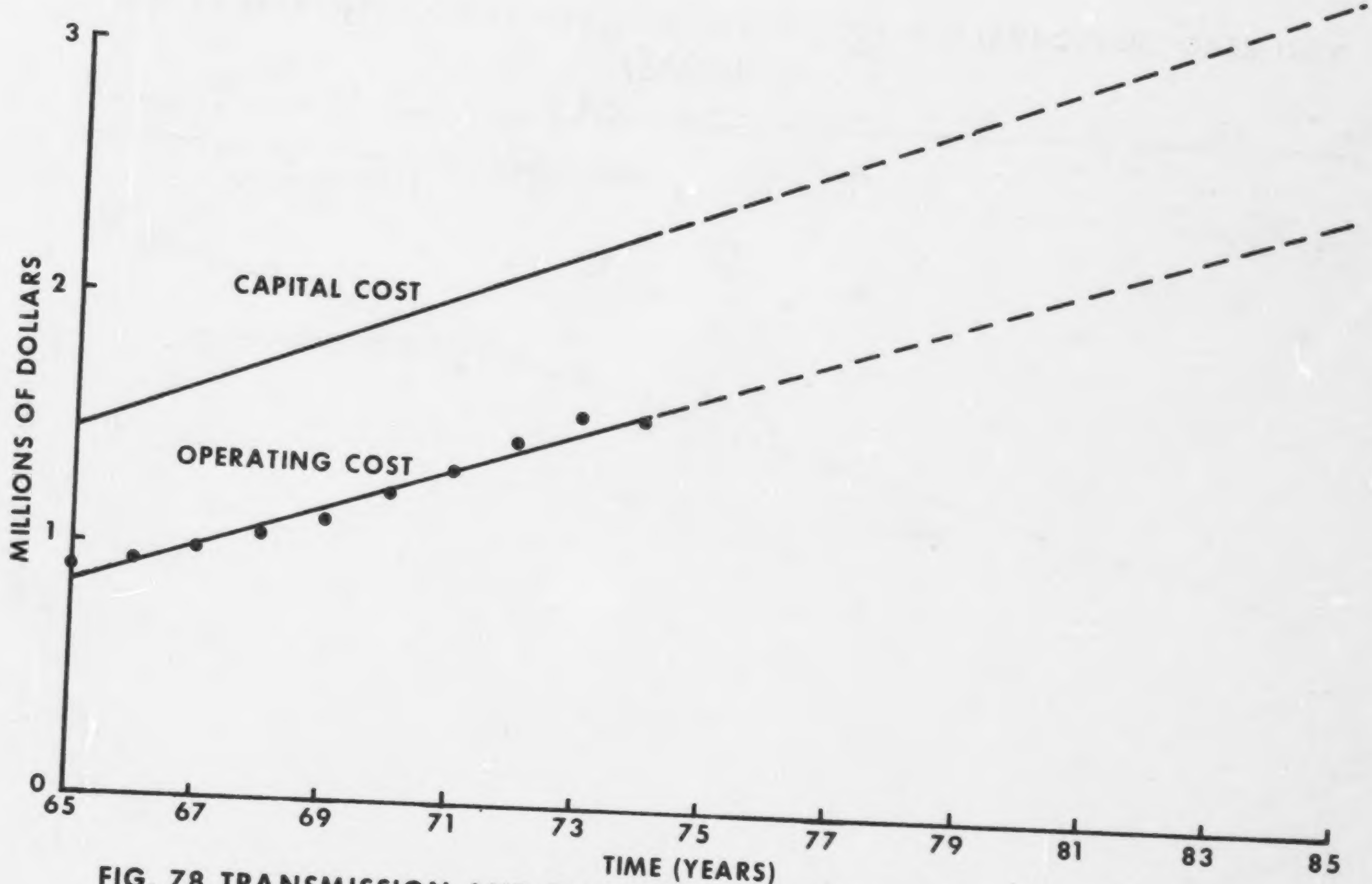

FIG. 78 TRANSMISSION AND DISTRIBUTION OPERATING AND CAPITAL COSTS EXTRAPOLATED OVER TIME.

TABLE 23. CURRENT AND PROJECTED AVERAGE EXPENSES FOR ALL 12 UTILITIES

Item	Cost		% Change
	1974	1984	
Total operating cost ($, millions/year)	8.81	14.8	+ 68
Total capital cost ($, millions/year)	3.8	5.7	+ 50
Total production cost ($, millions/year)	12.6	20.5	+ 63
Total unit cost ($/mil gal)	430	560	+ 30
Man-hours/mil gal	29.0	24.8	- 15
$/Man-hour	4.7	7.2	+ 53
Depreciation $/mil gal)	63.0	67.5	+ 7

replacing sand in the filter shell, and chlorine dioxide. From the previous analysis we learned that by the year 1984 our average utility will produce 120 MGD. It will therefore be assumed that any new treatment processes will be designed for a peak capacity of 150 MGD. Unit costs for each of the three technologies are shown in Table 24.

Figure 79 shows the CPI for the 10 years of analysis and for an additional 10 years, extrapolated in two ways. Based on conservative or straight line assumption, the CPI in 1980 is 1.9 (1965 = 1.0). Direct application of the conservative CPI to the 1975 unit costs yields the unit costs shown in the last two columns of Table 24. The new unit costs have been converted to annual costs and added to the expected treatment operating and capital costs in 1980, as shown in Figures 80 and 81. Beyond 1980 it is assumed that these incremental costs will be additive and at the same slope as the expected operating and capital costs. Figures 80 and 81 show that the adoption of GAC technologies will substantially increase treatment costs for the average water supply utility. Aggregating treatment costs with total capital and operating costs for the composite utility yields Figures 82 and 83. The percent increase in operating costs is much less than the percent increase in treatment cost alone. The impact on total production cost is shown in Figure 84, and the effect on unit cost is shown in Figure 85. Table 25 summarizes these cost increases.

Table 25 shows that the total production cost of water will increase by 36% between 1974 and 1980 without add-on technology. With the most expensive technology, total production costs will increase by 24% over those expected as a result of other pressures. Unit costs will increase by 24%.

The less conservative assumption regarding the increase in CPI would increase the add-on technology costs as shown in Figures 86 and 87. The increase in total water production cost, for example is 32%, and there is a 29% increase in unit cost.

The Effect of Time on Rate Structure - Without SDWA

As can be seen from the previous analysis, operating and maintenance costs will tend to dominate the cost of water supply over time due to the effects of inflation. Using data from all 12 utilities, we can formulate the following relationships for O&M and capital cost (Table 16):

$$OC = 360.4\ Q^{0.91}\ e^{0.056t} \qquad (r^2 = 0.93) \qquad (34)$$

$$CC = 193.8\ Q^{0.91}\ e^{0.043t} \qquad (r^2 = 0.86)$$

where OC = Annual operating cost in dollars

CC = Annual capital cost in dollars

Q = Annual revenue-producing water in mil gal/yr

t = Relative time starting with year 1

TABLE 24. UNIT COSTS FOR CONTROL TECHNOLOGY AT 150 MGD*[13]

Treatment Technology	Unit cost, 1975 ($/1,000 gallons)		Unit cost, 1980 ($/1,000 gallons)	
	Capital	Operating	Capital	Operating
Chlorine dioxide	0.2	1.0	0.24	1.22
Granular activated carbon (contactors)	4.1	2.2	5.00	2.68
Granular activated carbon (Media replacement)	1.1	4.0	1.34	4.88

* Costs are calculated at 70% of capacity.

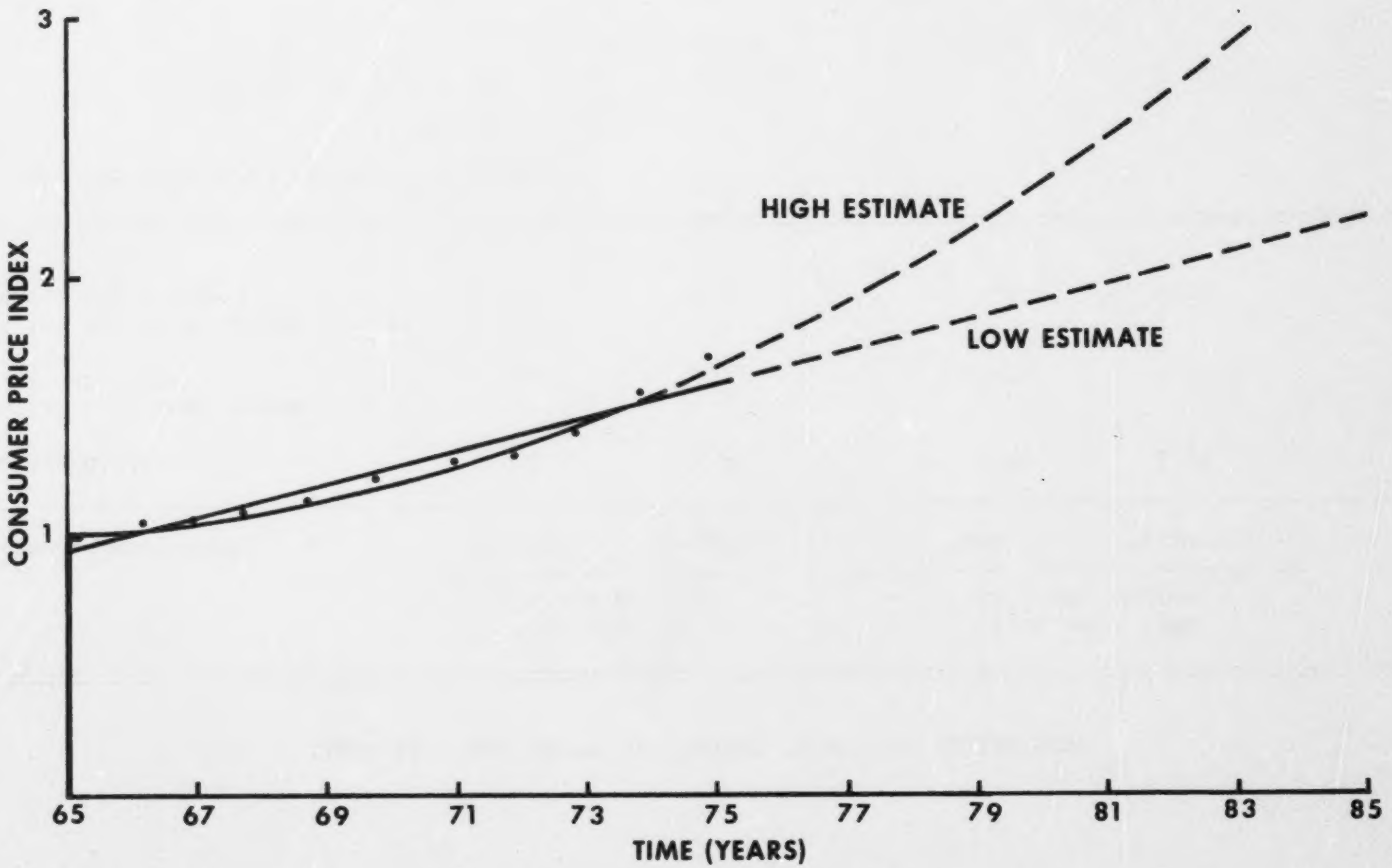

FIG. 79 CPI EXTRAPOLATED OVER TIME

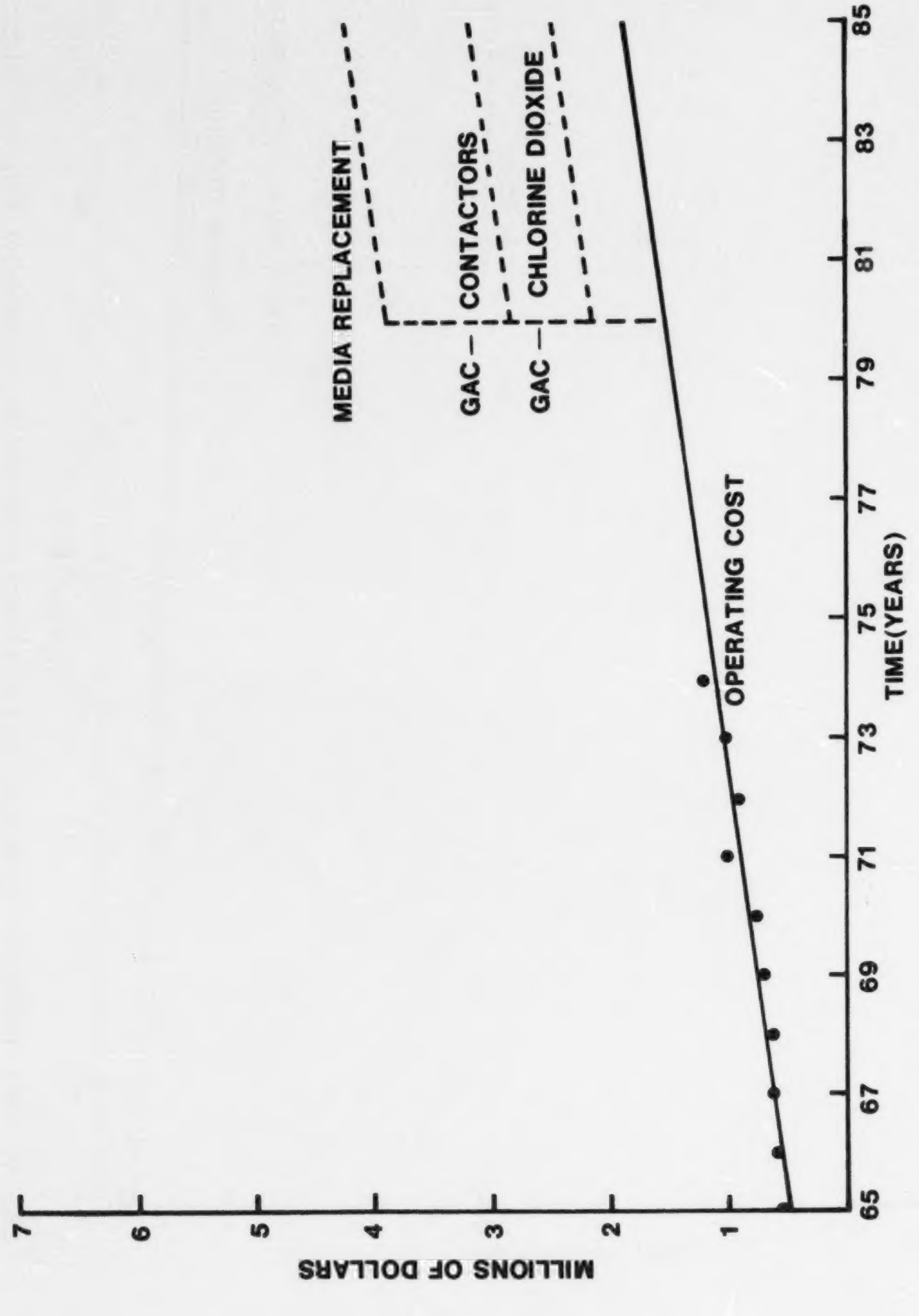

FIG. 80 TREATMENT OPERATING COSTS EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY

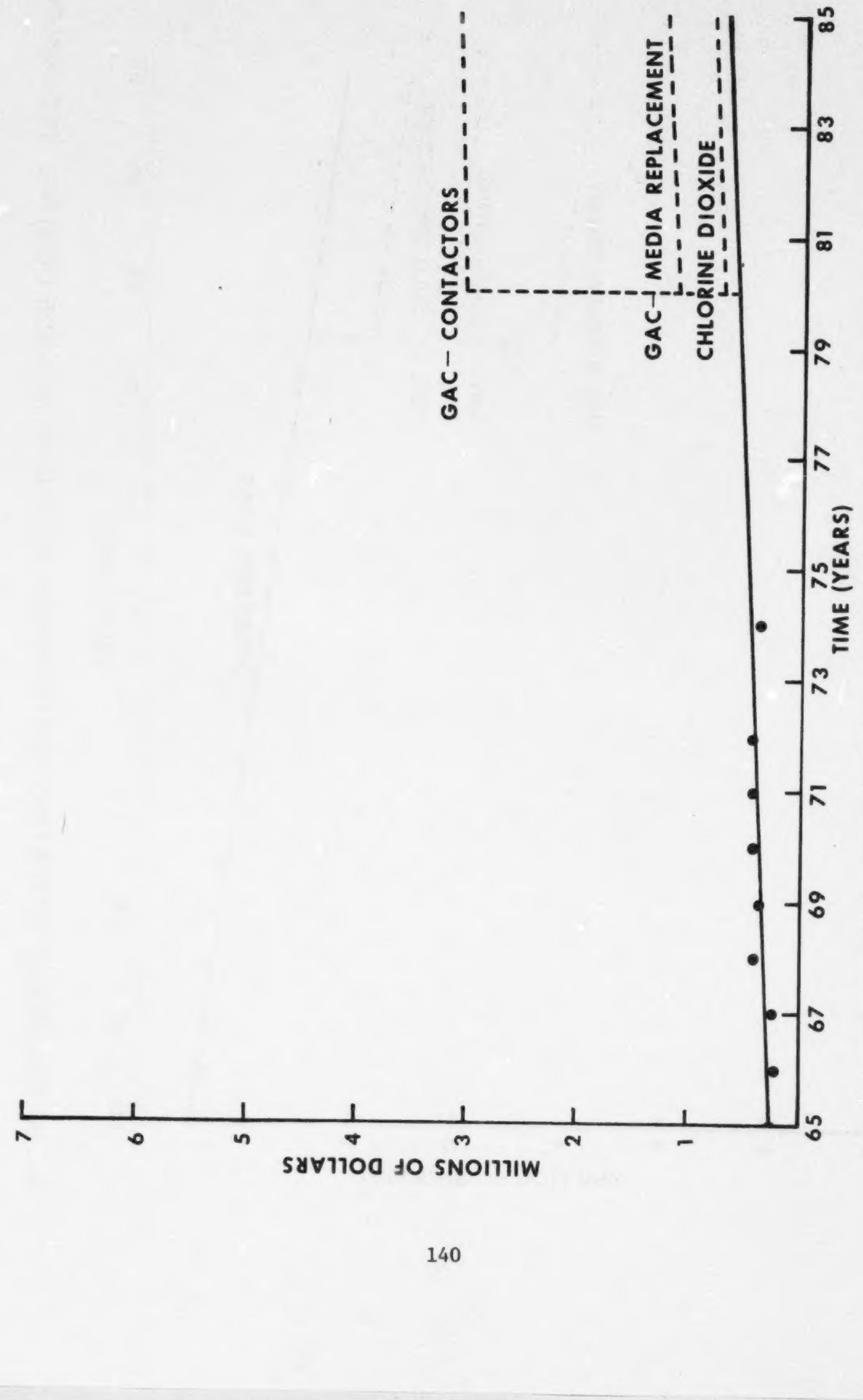

FIG. 81 TREATMENT CAPITAL COSTS EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY

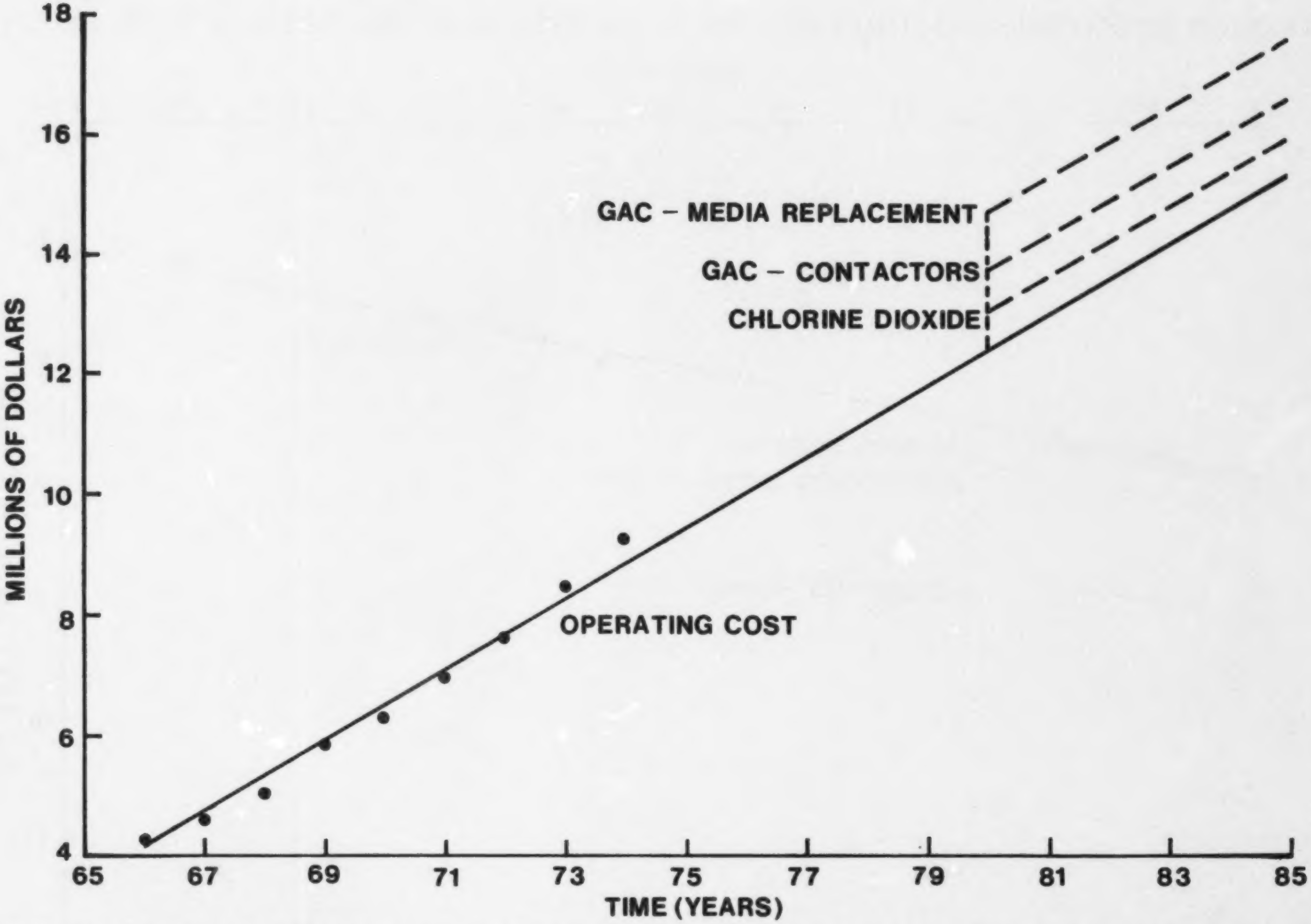

FIG. 82 TOTAL OPERATING COST EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY OPTIONS

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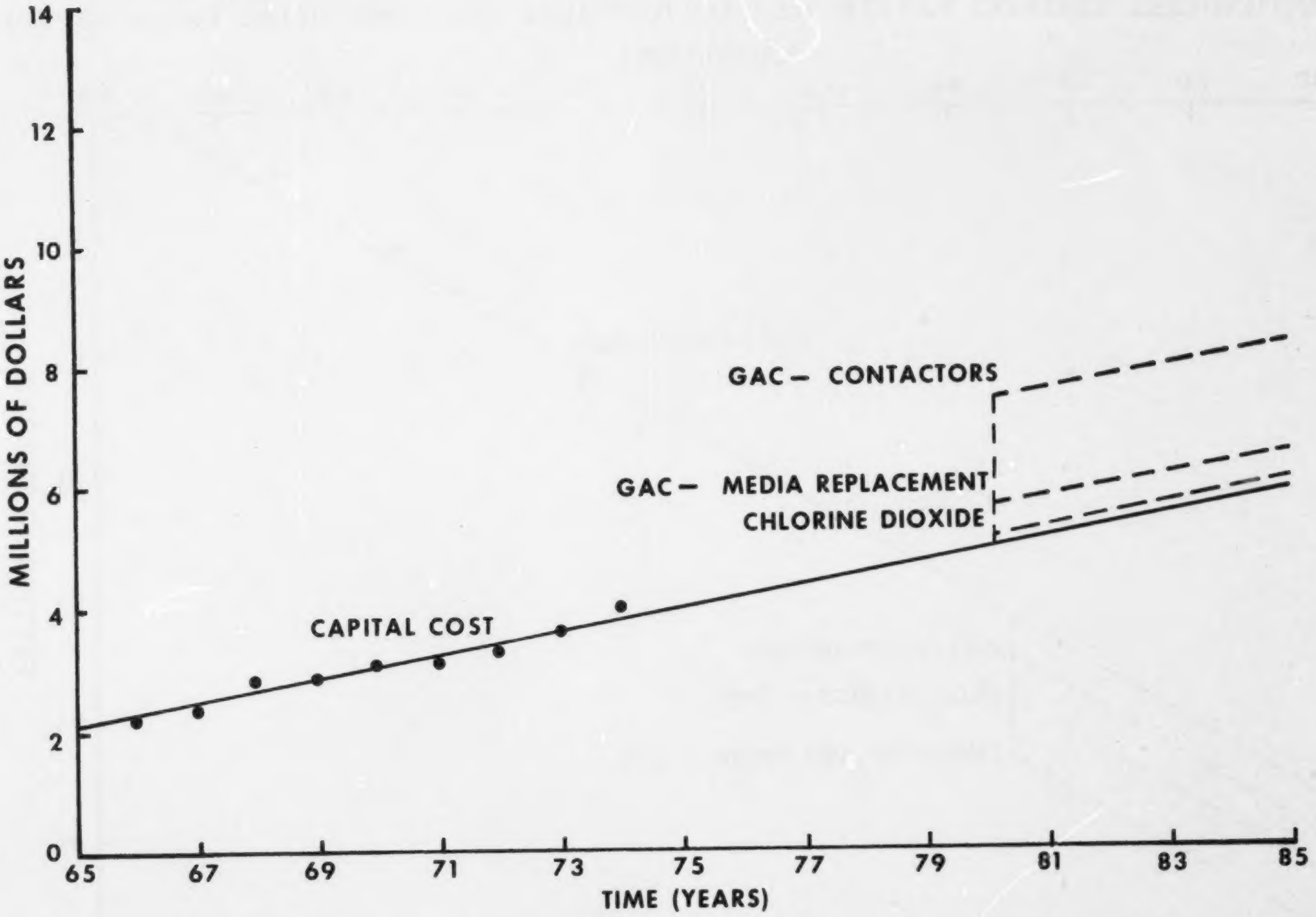

FIG. 83 TOTAL CAPITAL COST EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY OPTIONS

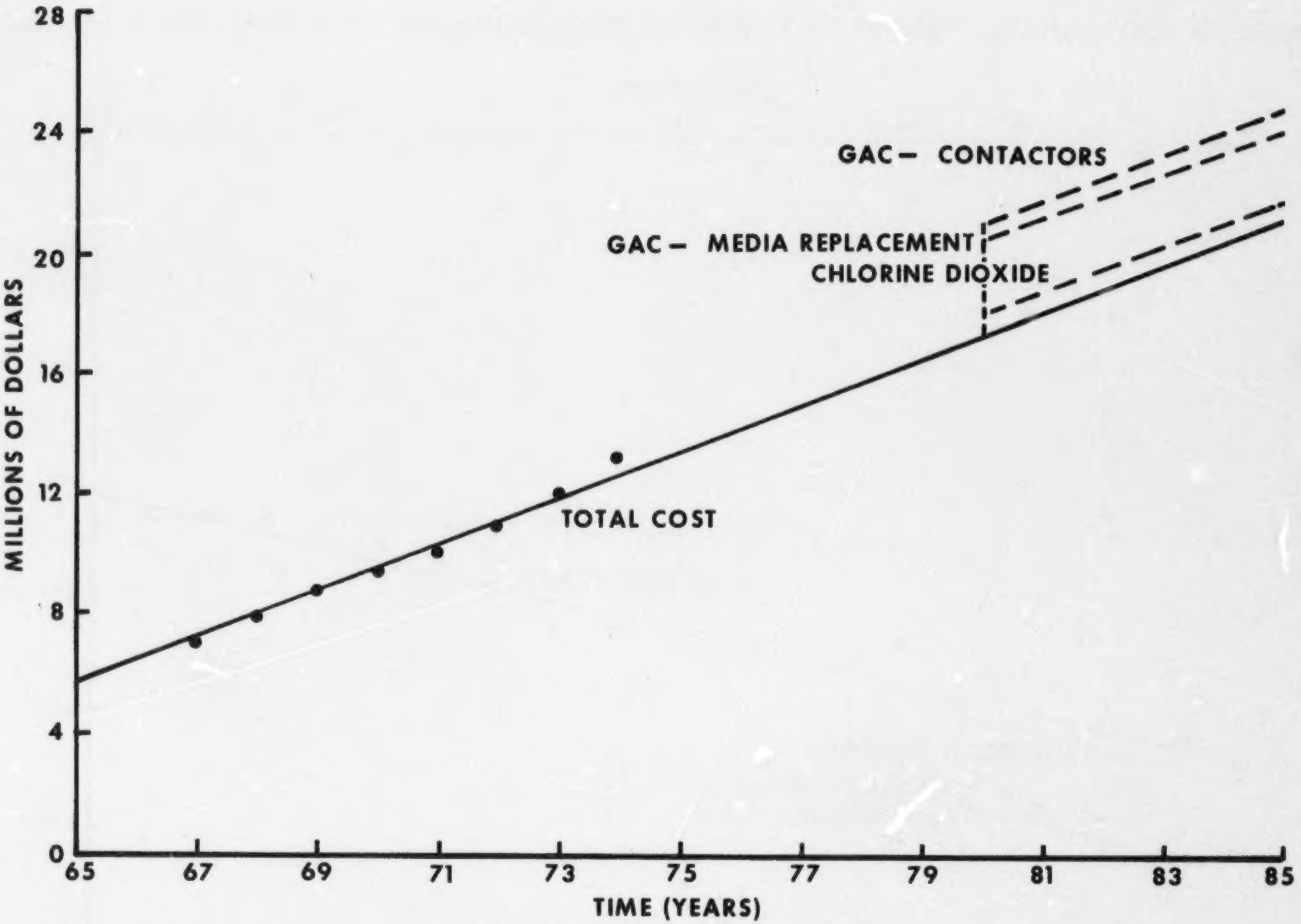

FIG. 84 TOTAL COST EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY OPTIONS

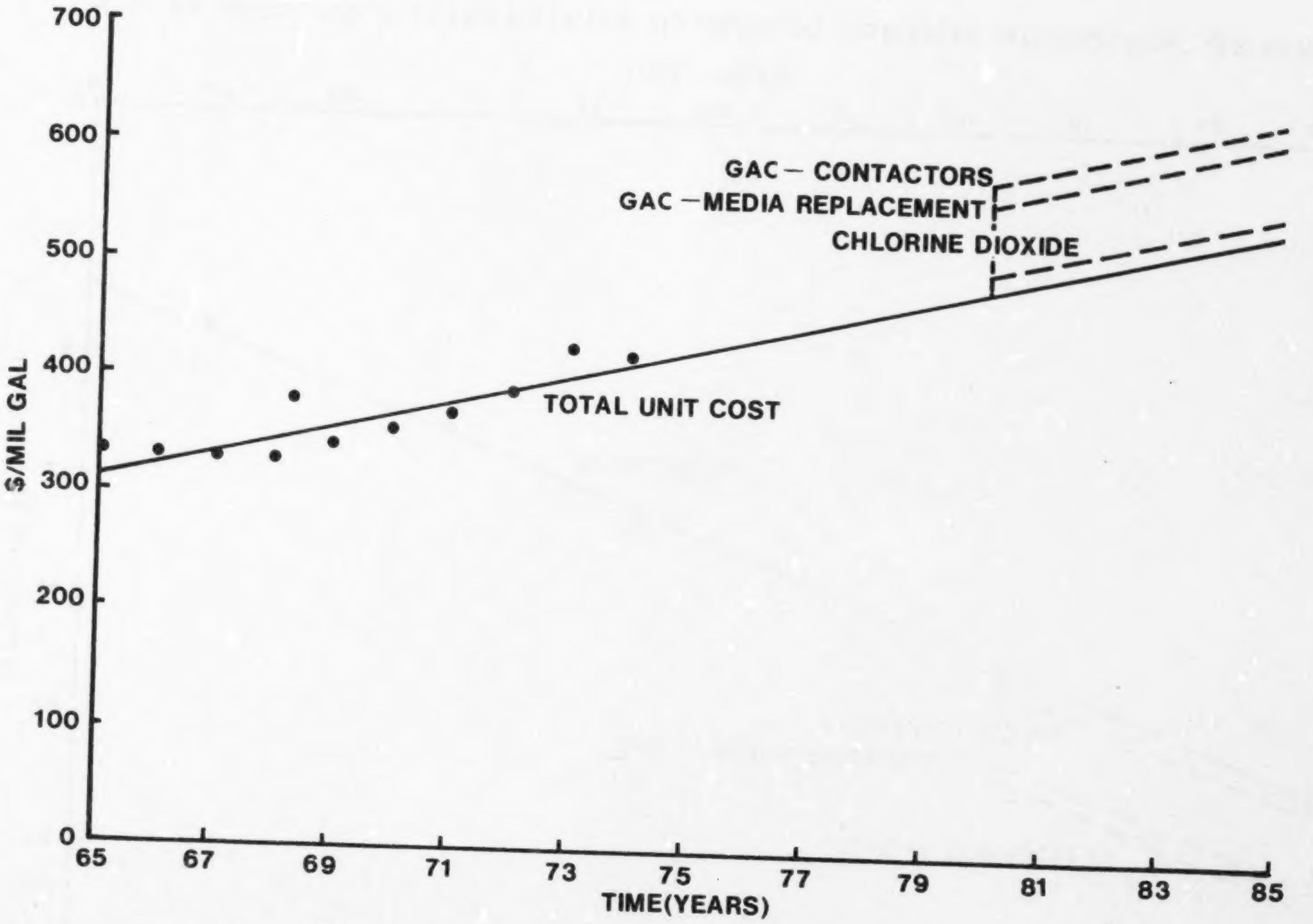

FIG. 85 TOTAL UNIT COST EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY OPTIONS

TABLE 25. EXPECTED COSTS IN 1980 FOR AN AVERAGE UTILITY

Item	Cost in 1975	Expected cost in 1980	Expected 1980 costs with add-on technologies		
			GAC -- contactors	GAC -- media replacement	Chlorine dioxide
Treatment operating cost (($/millions/year)	1.10	1.50	2.97	4.17	2.17
Treatment capital cost ($, millions/year)	0.48	0.60	3.34	1.33	0.73
Total operating cost ($, millions/year)	8.85	12.40	13.87	15.07	13.07
Total capital cost ($, millions/year)	3.80	4.95	7.69	5.68	5.08
Total production cost ($, millions/year)	12.75	17.35	21.56	20.75	18.25
Total unit cost ($/mil gal)	412.00	480.00	596.47	574.06	504.90

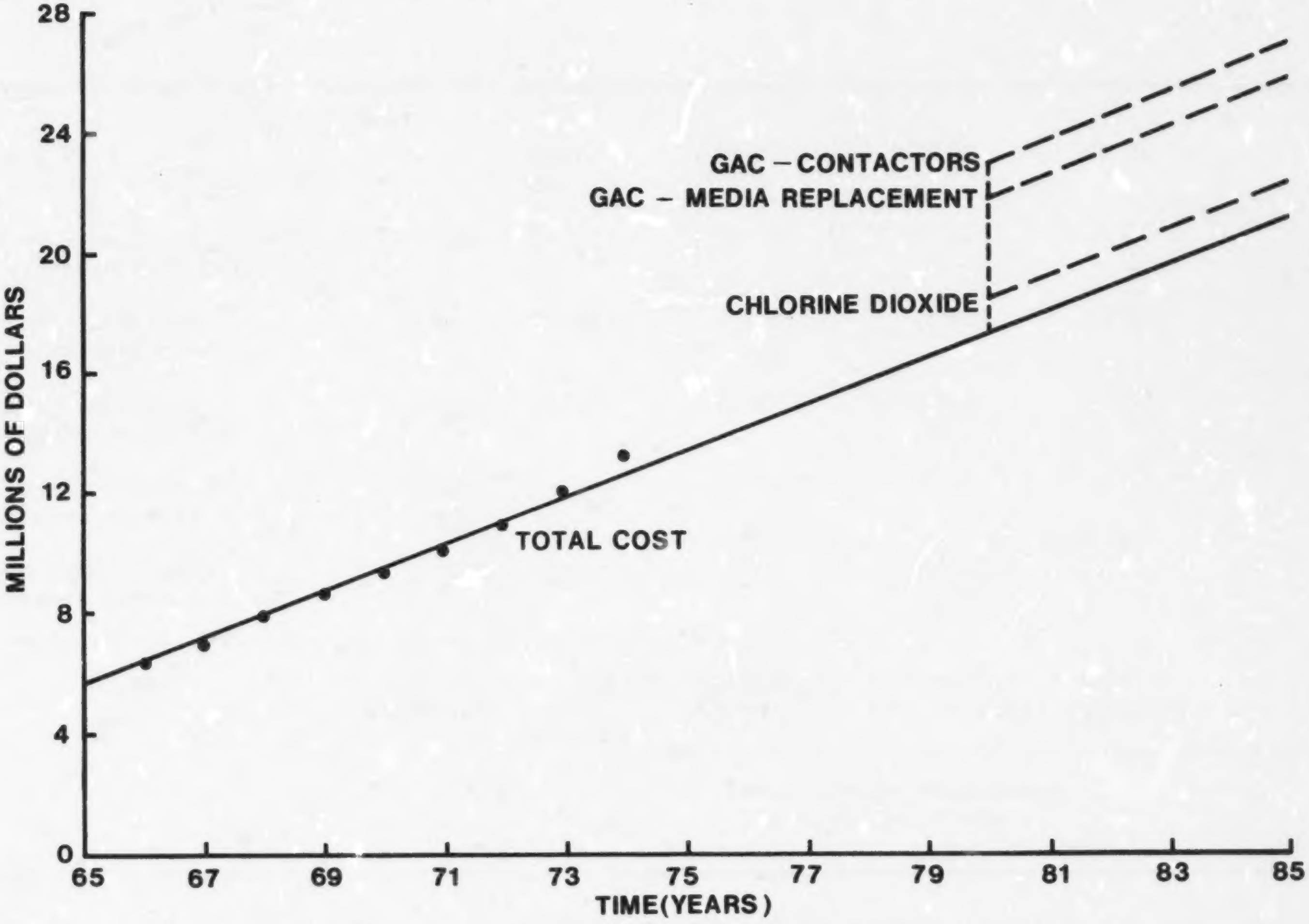

FIG. 86 TOTAL COST EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY OPTIONS: HIGH ESTIMATE

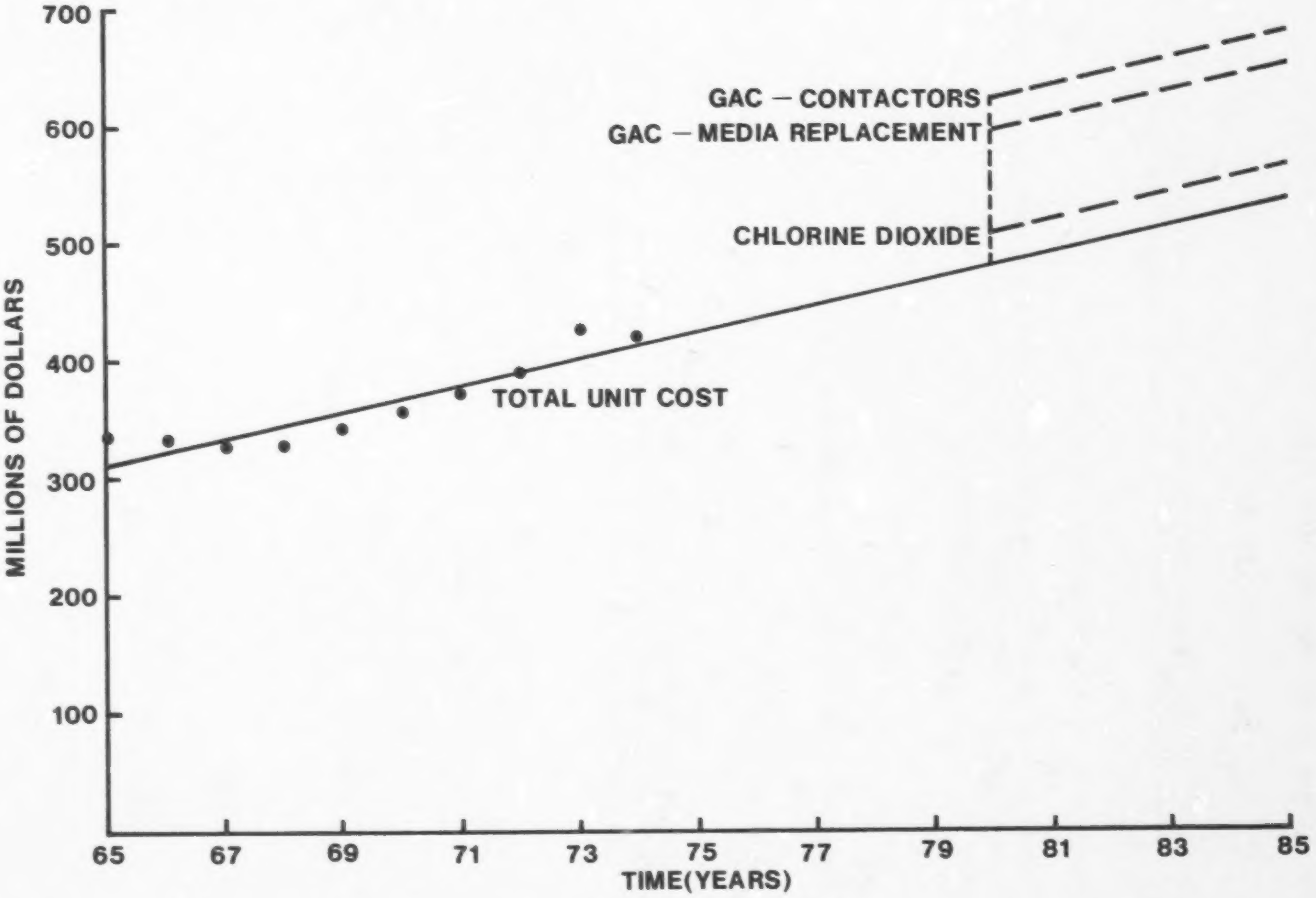

FIG. 87 TOTAL UNIT COST EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY: HIGH ESTIMATES

By formulating the ratio between operating cost and capital cost (Equations 34 and 35) we see the following:

$$\frac{OC}{CC} = 1.86\ e^{0.013t} \qquad (36)$$

From Equation 36 it can be seen that in terms of cost and ultimately the rate structure, water supply costs will be increasingly dominated by operating expenditures.

The Effect of Time on Rate Structure - With SDWA

Assume Equations 31 and 32 are the new capital cost equation and operating cost equation as shown below:

$$OC_n = 427.25\ Q^{0.91}\ e^{0.056t} \qquad (37)$$

$$CC_n = 219.64\ Q^{0.91}\ e^{0.043t} \qquad (38)$$

Forming the ratio of Equation 37 to Equation 38 yields

$$\frac{OC_n}{CC_n} = 1.95\ e^{0.013t} \qquad (39)$$

As can be seen from Equations 39 and 36, in a short period of time the new capital requirements resulting from the Safe Drinking Water Act will be insignificant when compared to total operating expenditures.

APPENDIX

The appendix contains regression equations for items of interest for each of the utilities studied. Time in the equations is in calendar years rather than in relative time.

APPENDIX

Cost equations are given for individual utilities over time. Both linear and exponential equations are presented.

TABLE A-1. ANNUAL OPERATING COST VERSUS TIME

Utility	Linear* $C = b + mt$			Exponential+ $C = Ke^{bt}$		
	b	m	r^2	K	b	r^2
Fairfax Co.	$- 2.94 \times 10^{7}$	464000	0.96	1.3	0.21	0.86
Elizabethtown	$- 4.40 \times 10^{7}$	765000	0.86	29000.	0.08	0.92
Kansas City	$- 2.93 \times 10^{7}$	521000	0.95	29000.	0.08	0.92
Pueblo	$- 6.32 \times 10^{6}$	114000	0.76	13000.	0.07	0.86
New Haven	$- 1.43 \times 10^{7}$	252000	0.97	10400.	0.08	0.97
Cincinnati	$- 2.56 \times 10^{7}$	472000	0.96	62500.	0.07	0.97
San Diego	$- 9.38 \times 10^{7}$	1.56×10^{6}	0.88	7700.	0.11	0.92
Orlando	$- 1.34 \times 10^{7}$	219000	0.90	370.	0.12	0.97
Dallas	$- 4.94 \times 10^{7}$	836000	0.94	10200.	0.10	0.97
Kenton Co.	$- 1.93 \times 10^{6}$	33900	0.92	1742.	0.08	0.97
Seattle	$- 2.96 \times 10^{7}$	517000	0.97	18300.	0.08	0.97
Phoenix	$- 4.68 \times 10^{7}$	791000	0.91	9712.	0.10	0.97

* C = annual cost in \$/year
b = constant
m = slope
t = calendar year

+ C = annual cost in \$/year
K = constant
b = rate of change
t = calendar year

TABLE A-2. ANNUAL CAPITAL COST VERSUS TIME

	Linear* $C = b + mt$			Exponential$^+$ $C = Ke^{bt}$		
Utility	b	m	r^2	K	b	r^2
Fairfax Co.	-4.33×10^7	690000	0.39	0.07	0.26	0.46
Elizabethtown	-2.44×10^7	404000	0.91	1285.	0.11	0.92
Kansas City	-3.97×10^6	88000	0.66	171000.	0.04	0.66
Pueblo	-6.54×10^6	108000	0.51	701.	0.10	0.66
New Haven	-2.68×10^7	447200	0.91	1695.	0.11	0.94
Cincinnati	994000	20500	0.10	1.31×10^6	0.01	0.10
San Diego	4.38×10^6	18200	0.06	4.70×10^6	0.01	0.06
Orlando	5.05×10^6	90759	0.53	11400.	0.07	0.53
Dallas	-2.52×10^7	448000	0.40	34200.	0.07	0.23
Kenton Co.	604000	10900	0.30	2037.	0.06	0.41
Seattle	-3.60×10^6	95900	0.91	353000.	0.03	0.93
Phoenix	1.18×10^7	18100	0.92	38300.	0.06	0.97

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in $/year
K = constant
b = rate of change
t = calendar year.

TABLE A-3. REVENUE-PRODUCING WATER VERSUS TIME

Utility	Linear* $C = b + mt$			Exponential$^+$ $C = Ke^{bt}$		
	b	m	r^2	K	r	r^2
Fairfax Co.	150000	2352	0.74	0	0.31	0.69
Elizabethtown	13200	680	0.52	8395.	0.02	0.50
Kansas City	19400	118	0.03	20500.	0.00	0.03
Pueblo	5902	4.65	0.00	5931.	0.00	0.00
New Haven	7970	135	0.03	9761.	0.01	0.04
Cincinnati	- 13674	718	0.90	8951.	0.02	0.90
San Diego	94800	1920	0.94	1166.	0.05	0.95
Orlando	28000	544	0.82	197.	0.05	0.80
Dallas	140000	2750	0.81	1080.	0.05	0.80
Kenton Co.	7090	126	1.00	7.98	0.08	1.00
Seattle	22800	338	0.01	26600.	0.01	0.02
Phoenix	141000	2690	0.76	854.	0.06	0.81

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

$^+$ C = annual cost in $/year
K = constant
b = rate of change
t = calendar year.

TABLE A-4. MAN-HOURS/MIL GAL VERSUS TIME

Utility	Linear* $C = b + mt$			Exponential+ $C = Ke^{bt}$		
	b	m	r^2	K	b	r^2
Fairfax Co.	- 37.39	0.88	0.24	2.01	0.04	0.20
Elizabethtown	30.22	- 0.23	0.46	44.28	0.03	0.20
Kansas City	77.70	0.48	0.03	96.04	- 0.01	0.03
Pueblo	14.74	0.39	0.04	22.10	0.01	0.04
New Haven	79.38	0.56	0.23	106.30	0.01	0.23
Cincinnati	88.14	0.83	0.86	200.35	0.03	0.85
San Diego	45.65	0.30	0.02	54.14	- 0.01	0.01
Orlando	39.48	0.03	0.00	38.01	- 0.00	0.00
Dallas	97.55	0.86	0.11	169.04	- 0.02	0.09
Kenton Co.	165.03	1.91	0.75	1849.39	- 0.06	0.77
Seattle	14.70	0.09	0.00	15.40	0.00	0.00
Phoenix	68.66	0.68	0.60	201.30	- 0.03	0.62

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in $/year
K = constant
b = rate of change
t = calendar year.

TABLE A-5. DOLLARS/MAN-HOUR VERSUS TIME

	Linear* $C = b + mt$			Exponential[+] $C = Ke^{bt}$		
Utility	b	m	r^2	K	b	r^2
Fairfax Co.	- 20.55	0.35	0.85	0.01	0.08	0.81
Elizabethtown	- 18.25	0.33	0.87	0.03	0.07	0.87
Kansas City	- 14.67	0.26	0.96	0.01	0.08	0.98
Pueblo	- 8.16	0.16	0.83	0.08	0.50	0.84
New Haven	- 20.94	0.35	0.97	0.01	0.09	0.96
Cincinnati	- 14.47	0.27	0.86	0.04	0.07	0.90
San Diego	- 20.17	0.35	0.78	0.01	0.08	0.86
Orlando	- 10.41	0.18	0.71	0.01	0.08	0.77
Dallas	- 10.91	0.19	0.85	0.00	0.10	0.74
Kenton Co.	- 7.19	0.16	0.34	0.20	0.04	0.34
Seattle	- 15.82	0.29	0.93	0.04	0.06	0.96
Phoenix	- 19.01	0.32	0.85	0.01	0.09	0.90

* C = annual cost in \$/year
b = constant
m = slope
t = calendar year.

[+] C = annual cost in \$/year
K = constant
b = rate of change
t = calendar year.

TABLE A-6. ANNUAL SUPPORT SERVICES COSTS VERSUS TIME (Operating)

Utility	Linear* $C = b + mt$			Exponential+ $C = Ke^{bt}$		
	b	m	r^2	K	b	r^2
Fairfax Co.	- 9.99	159000	0.84	35.	0.15	0.73
Elizabethtown	$- 1.22 \times 10^{7}$	204000	0.93	1138.	0.11	0.96
Kansas City	$- 1.38 \times 10^{7}$	242000	0.86	6894.	0.09	0.82
Pueblo	$- 2.50 \times 10^{6}$	43200	0.91	1289.	0.08	0.95
New Haven	$- 9.09 \times 10^{6}$	153000	0.96	1173.	0.10	0.99
Cincinnati	$- 1.14 \times 10^{7}$	149000	0.93	2006.	0.10	0.94
San Diego	$- 1.78 \times 10^{7}$	296000	0.93	1404.	0.11	0.97
Orlando	$- 5.64 \times 10^{6}$	91500	0.92	52.	0.14	0.92
Dallas	$- 2.52 \times 10^{7}$	403000	0.93	65.	0.15	0.97
Kenton Co.	- 586000	10200	0.84	355.	0.08	0.87
Seattle	$- 1.87 \times 10^{7}$	317000	0.98	3688.	0.10	0.97
Phoenix	$- 2.14 \times 10^{7}$	360000	0.97	5704.	0.09	0.99

* C = annual cost in \$/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in \$/year
K = constant
b = rate of change
t = calendar year.

TABLE A-7. ANNUAL ACQUISITION COSTS VERSUS TIME (Operating)

Utility	Linear* $C = b + mt$			Exponential$^+$ $C = Ke^{bt}$		
	b	m	r^2	K	b	r^2
Fairfax Co.	-2.44×10^6	38200	0.63	4.7	0.15	0.67
Elizabethtown	-6.24×10^6	106000	0.86	638.	0.11	0.71
Kansas City	---	---	---	---	---	---
Pueblo	- 934000	14200	0.35	0.00	0.23	0.58
New Haven	- 592000	14200	0.76	32000.	0.04	0.77
Cincinnati	- 818000	18000	0.74	22700.	0.04	0.76
San Diego	-6.8×10^7	(1.1×10^6)	0.83	1136.	0.13	0.88
Orlando	---	---	---	---	---	---
Dallas	- 639000	17400	0.14	81000.	0.03	0.13
Kenton Co.	- 107000	1818	0.57	27.70	0.09	0.67
Seattle	-1.13×10^6	22000	0.61	7277.	0.06	0.61
Phoenix	-4.64×10^6	72000	0.95	1.03	0.18	0.88

* C = annual cost in \$/year
b = constant
m = slope
t = calendar year.

$^+$ C = annual cost in \$/year
K - constant
b = rate of change
t = calendar year.

TABLE A-8. ANNUAL TREATMENT COST VERSUS TIME (Operating)

Utility	Linear* $C = b + mt$			Exponential+ $C = Ke^{bt}$		
	b	m	r^2	K	b	r^2
Fairfax Co.	- 771000	18800	0.32	44144	0.04	0.30
Elizabethtown	$- 3.43 \times 10^6$	58700	0.58	1515	0.09	0.66
Kansas City	$- 6.28 \times 10^6$	111000	0.94	6684	0.08	0.96
Pueblo	$- 1.29 \times 10^6$	24186	0.86	4839	0.06	0.92
New Haven	- 744000	14000	0.78	3300	0.06	0.70
Cincinnati	$- 1.8 \times 10^6$	41800	0.89	70700	0.04	0.91
San Diego	$- 3.4 \times 10^6$	59000	0.81	2135	0.08	0.85
Orlando	$- 4.5 \times 10^6$	73100	0.89	66	0.13	1.0
Dallas	$- 9.5 \times 10^6$	164000	0.90	5336	0.08	0.93
Kenton Co.	- 587000	10800	0.94	1584	0.07	0.97
Seattle	$- 2.9 \times 10^6$	47200	0.82	79	0.12	0.81
Phoenix	$- 7.3 \times 10^6$	121000	0.95	1138	0.10	0.93

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in $/year
K = constant
b = rate of change
t = calendar year

TABLE A-9. ANNUAL POWER AND PUMPING COST VERSUS TIME (Operating)

Utility	Linear* $C = b + mt$ b	m	r^2	Exponential+ $C = Ke^{bt}$ K	b	r^2
Fairfax Co.	-2.5×10^6	42000	0.93	445	0.10	0.92
Elizabethtown	-8.6×10^6	143000	0.45	2202	0.09	0.61
Kansas City	-4.7×10^6	90000	0.96	24700	0.06	0.93
Pueblo	- 13500	6470	0.52	75900	0.02	0.53
New Haven	- 232000	6606	0.11	30800	0.03	0.11
Cincinnati	-3.7×10^6	74000	0.87	34000	0.05	0.89
San Diego	---	---	---	---	---	---
Orlando	---	---	---	---	---	---
Dallas	-6.3×10^6	110000	0.89	5299	0.08	0.92
Kenton Co.	---	---	---	---	---	---
Seattle	---	---	---	---	---	---
Phoenix	-9.1×10^6	151000	0.63	1910	0.09	0.61

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in $/year
K = constant
b = rate of change
t = calendar year.

TABLE A-10. ANNUAL TRANSMISSION AND DISTRIBUTION COST VERSUS TIME
(Operating)

Utility	Linear* $C = b + mt$			Exponential+ $C = Ke^{bt}$		
	b	m	r^2	K	b	r^2
Fairfax Co.	-8.9×10^6	140000	0.77	37.9	0.14	0.83
Elizabethtown	-3.9×10^6	68400	0.91	4047.	0.08	0.94
Kansas City	-4.5×10^6	77600	0.89	1977.	0.09	0.87
Pueblo	-7.1×10^6	125700	0.79	8629.	0.07	0.89
New Haven	-2.7×10^6	50600	0.88	7729.	0.07	0.87
Cincinnati	-7.8×10^6	145000	0.97	17900.	0.07	0.96
San Diego	-4.7×10^6	101000	0.84	119000.	0.04	0.86
Orlando	-3.1×10^6	52800	0.70	740.	0.09	0.82
Dallas	-7.7×10^6	140000	0.89	15900.	0.07	0.91
Kenton Co.	-648000	11100	0.91	257.	0.09	0.95
Seattle	-6.9×10^6	130000	0.83	29400.	0.06	0.82
Phoenix	-1.4×10^6	219000	0.95	164.	0.13	0.99

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in $/year
K = constant
b = rate of change
t = calendar year.

TABLE A-11. ANNUAL TOTAL EXPENDITURES VERSUS TIME

Utility	Linear* $C = b + mt$			Exponential+ $C = Ke^{bt}$		
	b	m	r^2	K	b	r^2
Fairfax Co.	$- 7.28 \times 10^7$	1.15×10^6	0.63	0.57	0.23	0.58
Kansas City	$- 3.48 \times 10^7$	6.33×10^5	0.93	7×10^{-3}	4.95	0.91
Cincinnati	$- 3.75 \times 10^7$	6.76×10^5	0.63	2.44×10^4	0.086	0.46
Pueblo	$- 1.20 \times 10^7$	2.078×10^5	0.50	1.17×10^4	0.077	0.61
Dallas	$- 7.04 \times 10^7$	1.23×10^6	0.91	1×10^{-3}	5.61	0.96
Elizabethtown	$- 6.84 \times 10^7$	1.17×10^6	0.90	2.23×10^4	0.091	0.94
Kenton Co.	$- 2.53 \times 10^6$	4.48×10^4	0.80	3.16×10^3	0.075	0.90
Seattle	$- 3.32 \times 10^7$	6.13×10^5	0.97	9.41×10^4	0.066	0.98
Orlando	$- 1.86 \times 10^7$	3.13×10^5	0.86	2.90×10^3	0.10	0.94
San Diego	$- 8.94 \times 10^7$	1.54×10^6	0.88	4.04×10^4	0.087	0.92
New Haven	$- 4.67 \times 10^7$	7.97×10^5	0.95	9.13×10^3	0.098	0.96
Phoenix	$- 6.07 \times 10^7$	1.07×10^6	0.87	3×10^{-3}	5.24	0.94

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in $/year
K = constant
b = rate of change
t = calendar year.

TABLE A-12. UNIT COSTS ($/mil gal)

	Linear* $C = b + mt$			Exponential[+] $C = Ke^{bt}$		
Utility	b	m	r^2	K	b	r^2
Fairfax Co.	3.53×10^3	-42.2	0.56	5.37×10^4	-0.065	0.56
Kansas City	-1.18×10^3	21.8	0.93	3.14	0.067	0.91
Cincinnati	-3.29×10^3	8.55	0.95	26.9	0.033	0.95
Pueblo	-1.976×10^3	34.3	0.74	1.38	0.081	0.81
Dallas	-2.61×10^2	7.94	0.21	48.6	0.026	0.21
Elizabethtown	-1.46×10^3	26.4	0.92	2.66	0.071	0.93
Kenton Co.	3.87×10^2	0.59	0.00	397.	-0.002	0.00
Seattle	-6.33×10^2	12.0	0.74	3.53	0.058	0.74
Orlando	-6.46×10^2	13.7	0.60	14.7	0.044	0.58
San Diego	-7.29×10^2	17.0	0.59	34.7	0.037	0.62
New Haven	-2.25×10^3	39.67	0.92	1.66	0.082	0.94
Phoenix	-9.46×10^1	5.68	0.41	79.7	0.019	0.40

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

[+] C = annual cost in $/year
b = constant
m = slope
t = calendar year.

REFERENCES

1. Quarles, John R., "Impact of the Safe Drinking Water Act," Journal of the American Water Works Association, Vol. 68, No. 2, Feb. 1976, pp. 69-70.

2. "Safe Drinking Water Act," Public Law 93-523.

3. Clark, Robert M., and Gillean, James I., "The Cost of Water Utility Management." Proceedings of the Conference on Environmental Modeling and Simulation, April 19-22, 1976, Cincinnati, Ohio, EPA 600/9-67-016.

4. Hanke, Steve H., "The Theory of User Fees and Its Application to Water." Public Prices for Public Products (S. D. Mashkin, Editor). The Urban Inst., Washington, D. C. 1971.

5. Clark, Robert M., "Water Supply Economics," Journal of the Urban Planning and Development Division, ASCE, Vol. 102, No. UP1, Proc. Paper 12357, August 1976, pp. 213-224.

6. Clark, Robert M., Stevie, R., and Trygg, G., "The Cost of Municipal Water: A Case Study," Water Supply Research Division, Municipal Environmental Research Laboratory, U. S. Environmental Protection Agency, Cincinnati, Ohio 45268.

7. Clark, Robert M., Gillean, James I., Adams, W. Kyle, "Renovated Wastewater As A Supplementary Source for Municipal Water Supply: An Economic Evaluation," Municipal Environmental Research Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, Ohio 45268.

8. Clark, Robert M., "Cost and Pricing Relationships in Water Supply," Journal of the Environmental Engineering Division, ASCE, Vol. 102, No. EE2, Proc. Paper 12025, April 1976, pp. 361-373.

9. Dajani, J. S., and Gemmill, R. S., "Economic Guidelines for Public Utilities Planning," Journal of the Urban Planning and Development Division, ASCE, Vol. 99, No. UP2, Proc. Paper 9977, September 1973, pp. 171-182.

10. Engineering News Record, McGraw Hill Publishing Co., March 20, 1975, p. 63.

11. Orlob, Gerald T., and Lindorf, Marvin R., "Cost of Water Treatment in California," Journal of the American Water Works Association, Jan. 1958, pp. 45-55.

12. Clark, Robert M., and Goddard, Haynes G., "Cost and Quality of Water Supply," Journal of the American Water Works Association, Vol. 69, No. 1, Jan. 1977, pp. 13-15.

13. Clark, Robert M., Guttman, Daniel L., Crawford, John L., and Machisko, John A., "The Cost of Removing Chloroform and Other Trihalomethanes from Drinking Water Supplies," Municipal Environmental Research Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, Ohio 45268, EPA-600/1-77-008, March 1977.